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Search For Charmed Particles

Revised Fermilab Proposal 369

submitted by

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Abstract

We propose to use the CCM spectrometer to carry out a sensitive search for charmed particles produced in strong interactions at a nominal beam energy of 150 GeV/c. We limit ourselves to production in the beam diffraction region for reasons of acceptance and reconstruction. We present results of a test run undertaken in April 1975 to demonstrate the feasibility of K_s^o trigger, which we incorporate in the present proposal. Results of the test are combined with new insights which increase our sensitivity to charmed particle production by a large factor. We request a total of 2×10^{11} negative pions at a rate of 10^6 per pulse. With this illumination we estimate that we can measure a large number of hadronic decay modes. We make estimates of enhancements in mass spectra from charmed particle production and decay and calculate expected backgrounds using data from existing experiments. With conservative assumptions about the charmed particle model, we calculate effects corresponding to ten or more standard deviations in our most favorable channels.

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APPENDICES

I. Introduction

Perhaps the most pressing question in high energy physics today is: "Where are the charmed particles?" There is a spectroscopy of charmonium being rapidly filled in at SPEAR and DORIS[1] based upon the idea of charmed quarks, but as yet, no one has seen a long lived object with quantum numbers appropriate to a free charmed meson or baryon. In the past nine months, the theoretical basis for the existence of charm has steadily improved, but the experimental efforts to see it have been negative (with the possible exception of a single neutrino bubble chamber event).[2] The observation of prompt dimuons from high energy neutrino interactions[3] and a large production of prompt leptons[4] in pp interactions not coming from known sources provide additional tantalizing hints but cannot be taken as strong evidence by themselves. We must therefore consider it of prime importance to search for charmed particles with the maximum possible sensitivity, recognizing the complications of multi-body decays, branching ratio uncertainties, threshold effects, etc. We believe that we can maximize the sensitivity of experiment to charmed particle production in strong interactions, relative to any competing apparatus now existing or contemplated to exist in the foreseeable future. The essential points of our proposal are:

1. We choose to restrict our search for charmed particles to diffractive production of $D\bar{D}$ pairs. The restriction to diffractive interactions is implemented by requiring a recoil proton in the trigger corresponding to $\pi^- p \rightarrow p_{recoil} + X^-$ with $M^2_{x^-}$ between 12.5 and 45 GeV^2. With 2×10^5 bursts of 10^6 π^-/burst there will be $8 \cdot 10^7$ such diffractive events in our experiment. Assuming that 10^{-3} $D\bar{D}$ pairs are produced per diffractive interaction, we shall produce some 80,000 $D\bar{D}$ pairs in the experiment. With the deadtime of .03 sec of the spectrometer, we can accept up to 3×10^6 triggers in 2×10^5 bursts. Therefore an additional trigger requirement must be imposed. We propose two triggers in coincidence with the recoil proton.

a) A p_{recoil} trigger requiring a muon (called $p \cdot \mu$)

b) A p_{recoil} plus a $\Delta n = 2$ trigger requiring that the number of charged tracks 2 meters downstream from the target exceed the number of forward tracks leaving the target by $\Delta n \gtrsim 2$. (called $p \cdot \Delta n = 2$)

2. We have planned changes in the spectrometer to maximize the possibility of detecting neutral and charged K's. These changes are motivated by the theoretical prediction that both the hadronic and semileptonic decays of the D's will lead mostly to states with K mesons. We estimate that these changes will give:

Probability of identifying K° or $\bar{K}^\circ$ 20% (60% of K°_S)

Probability of identifying K^+ or K^- 30%

3. With the ($p \cdot \mu$) trigger and a 10% branching ratio for $D \to \mu + \nu + X$ we expect the following signals and backgrounds for $8 \cdot 10^7$ diffractive events:

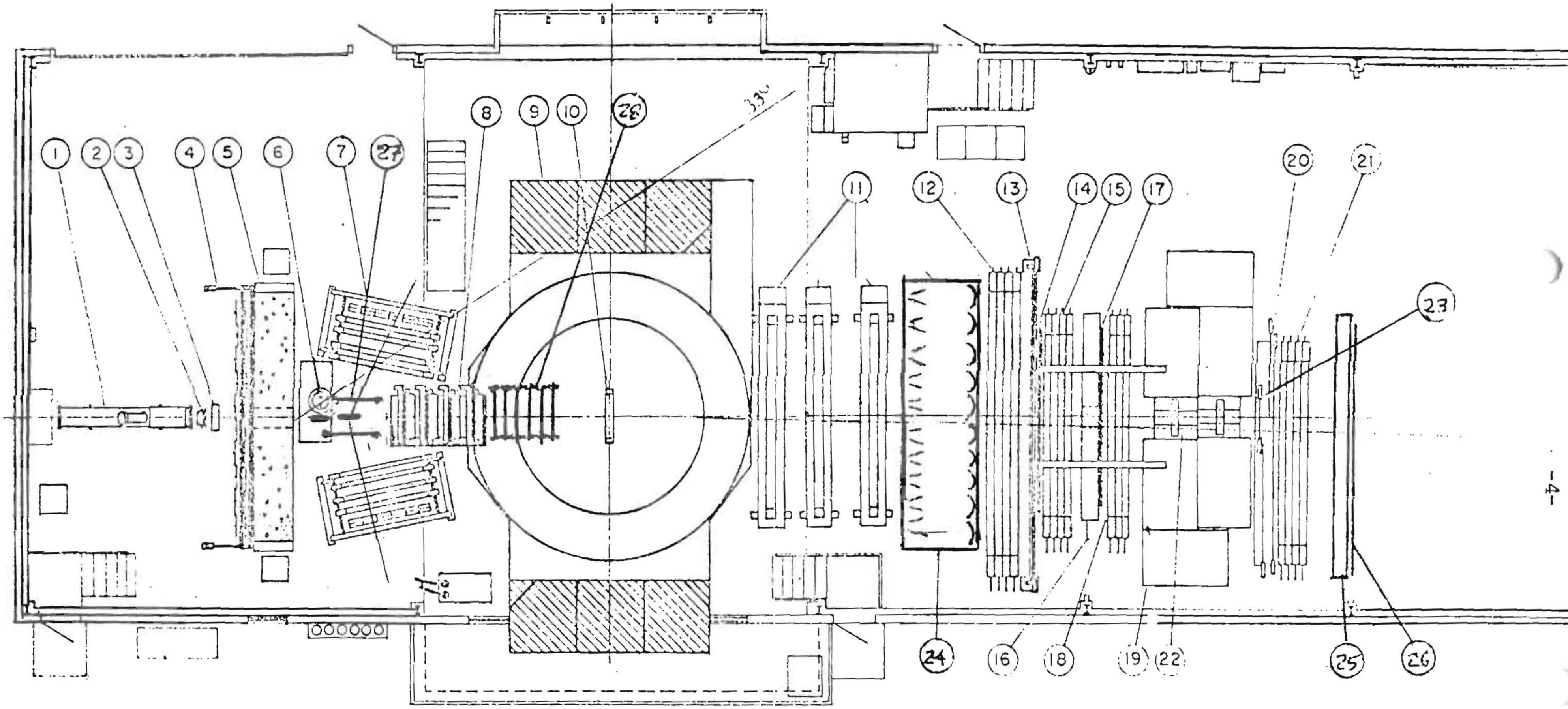
	Signal	Background	Significance
if K decays dominate	228	553	12 σ
if π decays dominate	912	5381	12 σ

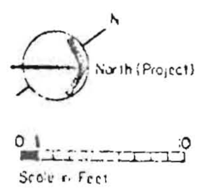
With the ($p \cdot \Delta n = 2$) trigger we expect the following signal and background:

	Signal	Background	Significance
Single K° events	530	10,000	5.3 σ
2 K events	90	40	14 σ

We have attempted to be conservative in estimating signal and background rates for the proposed triggers. We have, for instance, assumed that $K,n\pi$ decays will be dominated by $K,2\pi$ and $K,3\pi$ states. The probability of losing D's because of unmeasured π°'s is much higher in our estimates than if one accepts the estimates given by Lee, Gaillard, and Rosner,[8] or if one accepts the estimates in the discussion of the charm search using SPEAR.[9]

In addition to the triggers and yields summarized above, we have investigated other possible approaches to a sensitive charm search. One possibly promising approach using a two muon coincidence is described in Appendix E. Other schemes may occur to us as time passes, and we intend to remain alert for any good ideas. Meanwhile, before proceeding to the detailed discussion of what we presently propose, we first outline the current experimental situation with respect to charm and report on the trigger test which we undertook in April 1975. Many of the complex details have been relegated to Appendices. There is a single list of references at the end of the main text and a drawing of the CCM spectrometer as we intend to use it included in Fig. 1.





1 Cerenkov Counter
2 8"x8" Proportional Chamber
3 Hodoscope
4 Halo Veto Counter
5 Backward Scattering Shield
6 Liquid H_2 Target
7 Spark Chambers & Time of Flight System
8 8 - 1m x 1m Proportional Chambers
9 Cyclotron Magnet (4.3m dia. Poletip)
10 1m x 1m Proportional Chamber
11 3-2m x 4m Spark Chamber
   4 Shift Readout Planes/Chamber
12 2m x 6m Spark Chambers
   (8 Magnetostrictive Delay Readout Planes)
13 2m x 6m G Hodoscope
14 2m x 6m x 2" Steel Plate
15 2m x 4m Spark Chambers
   (8 Magnetostrictive Delay Line Readout Planes)
16 2m x 4m x 40.6cm Pb Absorber
17 2m x 4m H Hodoscope
18 2m x 4m Spark Chambers
   (8 Magnetostrictive Delay Line Readout Planes)
19 Steel Hadron Shield
20 2m x 4m M Hodoscope
21 2m x 4m Spark Chambers
   (8 Magnetostrictive Delay Line Readout Planes)
22 Removable Shutters
23 N Hodoscope
24 Multicell Čerenkov Counter
25 7M x 2.5M x 18" Pb Absorber
26 E331 Hodoscope Plane
27 Recoil PWC's
28 .8M x .8M PWC's

Fig 1
CCM SPECTROMETER

II. Evidence For and Against Charm

The strongest evidence for charmed quarks (as well as some worrisome evidence against) comes from SLAC and DORIS. Observation of $\psi(3095)$ and $\psi'(3684)$, now taken to be bound states of charmed quarks is the basic datum. The interpretation of ψ, ψ' as zero orbital angular momentum, radial bound states of $c\bar{c}$ with parallel quark spins (orthocharmonium) implies the existence of other states of the charmed quarks. In particular, a state of zero total angular momentum η_c should be found (paracharmonium) in which the quark spins are antiparallel. Such a state has now been seen at 2.75 GeV at DORIS as reported by Heinze and Wiik.[1/] Likewise, the $\psi'(3686)$ should decay by photon emission to P_c, the $\ell = 1$ orbital angular momentum state of $c\bar{c}$ and thence, again by photon emission, to $\psi(3095)$ the ground state of $c\bar{c}$. Observation of $\psi' \rightarrow \psi + 2\gamma$ with fixed gamma ray energies of 160 MeV and 400 MeV indicates the presence of the P_c state at 3.5 GeV or 3.2 GeV (there is a fundamental ambiguity as to which gamma is emitted first).[1/] Two more ψ related states have been observed at SPEAR, one of which is probably the DESY P_c.[1/] The narrowness of the ψ states is taken as evidence for the stability against annihilation of the quark-antiquark bound state (Zweig's Rule). The fact that the charmonium spectroscopy is seen in such remarkable detail has to be viewed as strong evidence for a charmed quark interpretation.

The charm model's addition of another quark of charge + 2/3e also helps explain the large ratio R of hadron to lepton production in e^+e^- annihilation, this result, however, is not by itself very compelling, since color and further effects must still be invoked to explain the measured R value of 5. The asymptotic colored four quark limit of R = 3.3 might, of course, be approached from above rather than below. Harari has advanced the speculation[5/] that the discrepancy can be explained by pair production of a new heavy lepton which decays both semi-leptonically and purely hadronically. This speculation is based upon the observation of opposite sign electron-muon pairs unaccompanied by other leptons in e^+e^- annihilations above about 4.1 GeV total CM energy at SPEAR.[6] This signal is interpreted as evidence for production of a new heavy lepton pair and could account for the additional increase in R above the 4.1 GeV region not accounted for by charmed quarks.

Heavy leptons *per se* are relevant to the charm question since their hadronic and semileptonic decays are likely to be deficient in strange particles and thereby offset the expected rise in the fraction of inclusive kaons above the threshold for charmed particle production.[5] This speculation might perhaps be viewed, however, as a theorist's rationalization of one of the most worrisome pieces of evidence against the charm theory, namely the non-observation of a significant increase in the fraction of inclusive kaons above the charm threshold.[7] If the overall increase of R above 4.1 GeV at SPEAR is even partly due to the production of real charmed particles, it seems unavoidable* that the K/π should experience a significant increase.[8] No change has been observed.[7] This problem, combined with a negative result in a search for charmed particles by reconstruction of invariant masses from favorable charged particle combinations using final state hadrons at SPEAR, constitutes the serious evidence against charm alluded to earlier.[9] There is no convincing rationalization available at the moment for the search result, and it must be taken at least as a limit on the branching ratio into these channels. These limits are discussed in Appendix B as they relate to the present proposal.

Another source of support for the existence of charmed particles comes from neutrino interactions at high energy. Nominally, the strongest evidence comes from a single event in a BNL neutrino bubble chamber exposure. Here, an interaction was observed which seems to have as its most probably explanation the production and decay of a charmed baryon of mass 2.426 GeV.[2] Other interpretations were dismissed as highly improbable. The initiating neutrino had an energy of 13 GeV, but preliminary results from a higher energy neutrino exposure in the 15' chamber at Fermilab showed no similar event candidates, although the sensitivity

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* A possible way out was advanced by DeRujula, Georgi, and Glashow by the introduction of right handed currents, but this only helps by a factor of two or so.[16]

should have been greater by a factor of about 100.[10] No explanation of this situation is possible; however, one event is never conclusive proof of anything.

A less direct, but more established effect is the observation of prompt dimuons from neutrino interactions in steel and scintillator observed at Fermilab.[3] There, about 1% of the neutrino interactions produce a second prompt muon in addition to the neutrino associated muon whose energy and transverse momentum distributions are consistent with those expected for charmed particle production. The experimenters take this as persuasive evidence for the existence of charmed particles and the production rates taken at face value predict a branching ratio to muons of about 10%.[11] We incorporate this evidence in our calculations of trigger rates and branching ratios.

Finally, the most solidly documented piece of evidence, though the least specific to charm is the observation of prompt electrons and muons from strong interaction events at large values of $p_\perp$. There are by now, many experimental observations of the phenomenon, and all agree that the inclusive ratio of prompt leptons to pions, for $\sqrt{s} > 10$ GeV, is $R_{\pi\ell} = 1.0 \pm .2 \times 10^{-4}$ for $p_\perp > 1.5$ GeV/c.[4] There is, unfortunately, very little published data as $p_\perp \to 0$, and we have to admit to uncertainty in the value of $R_{\pi\ell}$ below $p_\perp = 1.0$. A Penn-SUNY collaboration measured ℓ/π down to $p_\perp = 0.6$ at BNL energies and found a tendency of R to rise by as much as a factor of 2. This data has not yet been published. Similarly, the CCRS Group at ISR reports a rise in $R_{\pi\ell}$ at small $p_\perp$ at high S, but again, this data has not yet reached the publication stage.[4]

The fraction δ of $R_{\pi\ell}$ which <u>cannot</u> come from sources already known (ρ, ϕ, $\omega \to \ell$'s etc.) varies between 0.5 and 1.0, so we ascribe this to charmed particles and use it to predict our triggering rates. In one approach to the present experiment, sparked by discussions with the MIT group, we propose to examine in detail the class of events with single prompt electrons independent of whether or not they come from charmed particle decays. This would help us understand the production mechanism, independent of its specific origin. We hope, of course, that it will turn out to be due to the leptonic decays of charmed mesons and serve as a trigger for their observation in both the muon and electron modes.

Taken at face value (see Appendix B) the prompt (strong interaction) leptons already seen predict a production cross section times branching ratio of $\sigma(D\bar{D} + x)B_{\mu} = 2\times10^{-4}\ \sigma_{T(\mathrm{inel.})}$. Taken together with an assumed branching ratio to muons of 0.2 from the dimuon neutrino experiment, we get a predicted inclusive charmed pair production cross section of $\sigma(D\bar{D} + x) \leq 0.001 \times \sigma_{T(\mathrm{inel.})} = 20\mu b$.

This is an uncertain estimate and could decline by a factor of two or more[8]. It suggests that sensitivities of a few microbarns for total charm production will probably be needed. This implies, of course, appropriate lower limits for the product of σB_i, the cross section times branching ratio into individual reconstructable final states. We discuss these specific limits in Appendix B.

The evidence against charm in strong interactions comes from three main sources: a) a few experiments have attempted to see a mass peak in some of the expected decay channels and failed (there are few attempts so far reported and only weak limits,[12,13,14] b) there is no clear energy dependence to the prompt lepton production,[4] c) no energy threshold effect has been observed in the kaon/pion inclusive production cross sections.[15] The laboratory beam energy threshold for production of $D\bar{D}$ in πp interactions should be around 15 GeV. If there is no strong suppression immediately above threshold, the ratio of K/π should experience a step increase (or at least a rapid rise), and this K/π ratio should be paralleled by the onset of prompt lepton production. The expected rise is not seen[15] and the energy dependence of prompt leptons is uncertain at the present moment.[4]

These observations can be taken to reflect on our proposed search in the following way. First, if the neutrino dimuon events are correctly interpreted as charm production, they imply branching ratios to leptons of about 10%. If this is true, and if the SI prompt leptons come from the same source, then the total inclusive charm production is at the 10^{-3} level (see estimate above) and the K/π ratio will change only imperceptably above threshold. The K/π ratio in SI, therefore, is not a good test, nor should it constitute a serious limit on charm. The prompt lepton threshold, on the other hand, should be a sensitive indicator of the charm threshold. Unfortunately, there is no agreement as to whether there is, or is not, a threshold for prompt leptons in SI. Pending clarification, we must leave this test an open issue and ignore its influence on the proposed search. Counter evidence for charm in items b) and c) is therefore not persuasive yet.

The experiments which have so far reported limits on charm can be characterized as being statistically weak,[14] very specialized,[12] at relatively low energy,[13,15] or a combination of the above. This is in no way intended as a criticism of these efforts, but rather points out the difficulty of observing the phenomenon sought. In our own calculations, we have been made painfully aware of the extreme difficulty (from kinematics alone) of capturing and reconstructing enough particles to see the typical multiparticle final states of charmed particle decays. Experiments handicapped by low statistics, lack of particle identification, and especially those limited by restricted momentum acceptance can hardly hope to do as well. We conclude that the limits from category a) are not conclusive proof that charm is absent in SI at our level of sensitivity.

Let us summarize the pros and cons at this point: The pros are mostly from e^+e^- annihilations into the ψ family (whose charmonium spectrum is seen in dramatic detail), and from neutrino interactions where the prompt dimuons have all the desirable properties of charm production and decay. Enticing hints and valuable limits come from the prompt leptons in SI's. The cons come from the negative search results for charm production in SI's, the non-observation of charmed mesons above 4.1 GeV at SPEAR, and the muddled situation at low S for prompt leptons from SI's. The second limit is the most worrisome and we take this as an indication that the prompt lepton source must be uncovered regardless of the existence or non-existence of charm. Accomplishing this last goal will require us to trigger on electrons and reduce the event sample to one with a large signal to background ratio of prompt, single electron events. This is the principal goal of the MIT people, with whom we have had discussions about a possible joint search. We hope, of course, that the charmed particles appear before we reach this rock-bottom sensitivity level, but we are planning for any eventuality. We now proceed to a review of our P-369 test run of last spring, and discuss its relevance to the present modified proposal.

III. Results of P-369 Test Run

The preliminary version of this proposal was submitted to Fermilab on December 6, 1974, closely following the discoveries of J at BNL and ψ, ψ' at SLAC. In the three month period following, the proposal was reviewed and approved for a test run to establish the utility of a novel K_S^o trigger to be used as a means of isolating charm-rich inelastic interactions. Subsequent action on the proposal was to await the outcome of the test. The test run itself depended upon arranging the initial use of the CCM Spectrometer by a group other than the E-98 muon collaboration. Some difficulties were encountered, but cooperation adequate to accomplish the goal was attained and the test took place in April 1975. We reported briefly at the end of the test to Jim Sanford at Fermilab and promised a full report and/or modified proposal in the fall. This document is that proposal and it updates and supersedes the preliminary version. The present section will discuss the test results and relate them to the estimates in the preliminary proposal.

Our spring test had as its primary goal, demonstration that we could preferentially trigger on inelastic collisions with two neutral kaons (or a kaon and a lambda) in the final state. We succeeded in doing this for the trigger itself, but lacking good experimental data, the estimate for the inclusive K_S^o momentum spectrum used in the preliminary proposal was not correct. We now have accurate values.[19] This problem caused the acceptance for kaon decay in the active decay space to decline from the estimated value of 0.7 to the measured value of 0.4. This number appears as a square in the reconstruction rate for two particles, so we lost a factor of 3 at this stage relative to the proposal estimate. Worse still, since the acceptance of the apparatus for track reconstruction cuts off sharply below a neutral kaon momentum of about 10 GeV, the misestimated momentum spectrum problem thereby hurt us again and caused the net recovery rate of double K_S^o to fall below the estimate by a factor 4. Our ignorance of the correct inclusive K_S^o spectrum thereby hurt us essentially as a fourth power for the 2 K_S^o trigger, and rendered it impractical as originally conceived. During the run itself, we were lulled into a sense of security by a bizarre and unexpected source of background triggers which fortuitously compensated for the missing $K_S^o K_S^o$ rate and caused the net observed trigger rate to come out to the expected value. The bad trigger source originated in the tape covering the beam hole in our halo veto counter, and being considerably upstream of the actual target was able to cause fake $\Delta n = 2,4$ triggers by missing the first counter and hitting the second in the Δn trigger combination. The problem is trivially removable, but it kept us from being alarmed by our observed trigger rates. The numerical details of this situation are discussed in Appendix A.

The single K_S^o reconstruction rate was closer to the estimate in the proposal, but still suffered from the momentum spectrum problem. Once this situation was corrected in the calculations, we found that we could understand and reproduce essentially all the observed rates. The conclusions we draw from the corrected estimates are as follows:

1) The idea of using analog pulse heights in two counters before and after the decay region worked essentially as planned (see Appendix F).

2) The background trigger source from interactions in the Δn counters and from the Landau tails of the pulse height distributions were about as predicted.

3) The poor acceptance of the CCM spectrometer for low momentum tracks, and especially for low momentum kaons caused us to rethink our initial plan to trigger on small x interactions. We now consider it important to restrict the trigger by means of a recoil proton to a limited missing mass "blob" moving rapidly forward. This point is explained and elaborated in Sections IV, V, and Appendix C.

4) We learned that the low momentum acceptance can be substantially improved by the addition of more PWC planes just inside the upstream magnet poles. This lesson was also made clear to the E-98 experimenters by the inclusive hadron analysis. We are now building the appropriate PWC's at Illinois to alleviate the problem.

5) Lastly, and in some respects most importantly, we learned that we could operate the CCM spectrometer successfully and analyze the data in a reasonable time. We believe the present revised proposal is strengthened by the test run and our approach to the charm search made more effective by what we learned. We present our ideas in the remainder of the proposal. The detailed numbers from the test run comparison are given in Appendix A.

IV. Experimental Plan and CCM Spectrometer

We propose to exploit the unique properties of the existing spectrometer in the muon laboratory at Fermilab to search for evidence of production and decay of charm-anticharm meson pairs. In planning this experiment we have implicitly assumed that the decays are not dominated by some simple decay mode such as $D^\circ \to K^- \pi^+$, since if this is the case, we expect that this will show up in other more specialized searches. We have instead supposed that we have to look for and find multibody decays, such as $D \to \bar{K}\pi\pi$ and $D \to \bar{K}3\pi$.

If charmed mesons do indeed exist, but decay mainly into fairly complicated decay modes, one is led to the conclusion that one must look for them in an experiment using a spectrometer of uncommonly large acceptance. Reasonable guesses about production rates and the fraction of reconstructable decay modes, make it look extremely unlikely that a bubble chamber can do the job in spite of its almost ideal acceptance properties. Even given the very high acceptance of the CCM spectrometer ($\sim \pm$ 90 mr) it seems clear to us that one has a reasonable reconstruction efficiency only for D's produced with a large forward momentum (forward x). This circumstance seems to leave us only two choices for a successful experiment:

(a) Use a spectrometer with a vertex detector, like Ω or a streamer chamber.

(b) Restrict the trigger to event topologies likely to contain charmed pairs with both D and $\bar{D}$ carrying a substantial fraction of the incident momentum.

We have opted for the second choice; we propose to limit our search to events of the type:

$$\pi^- p \to p^+ X^- \quad ; \quad 12 \lesssim M_x^2 \lesssim 40 \text{ GeV}^2 , \qquad p_{inc} = 150\text{–}250 \text{ GeV}$$

The choice of π^- as the incident beam is suggested by criteria of simplicity; we choose to defer the search for charmed baryons to a second stage since there is no reason to believe that it is easier to produce $M_{\bar{c}} B_c$ than $M_c M_{\bar{c}}$. By restricting our choice to diffractive $D\bar{D}$ production we are making a deliberate gamble, namely that the fraction of all diffractive events leading to $D\bar{D}$ is no worse than the fraction of all inelastic interactions leading to $D\bar{D}$ production. We are encouraged in making this gamble by the observation that in the reaction $\pi^- p \to pX^-$ ($M_{X^-} \lesssim 2.5$ GeV, $p_{inc} = 40$ GeV) the fraction of events with K^+K^- and $p\bar{p}$ is similar to that in an unrestricted interaction [note that at 40 GeV one is quite close to the $p\bar{p}\pi$ threshold][22/] If our guess turns out to be correct, we will have not only the advantage of a good acceptance for detecting single D decays and reasonable acceptance for doubles, but also the further advantage of observing $D\bar{D}$ pairs accompanied by few extra particles (or none). Since we will be looking at clusters with masses not far above $D\bar{D}$ threshold, it seems reasonable to guess that most $D\bar{D}$ events will be of the type:

$$\begin{aligned} X^- &\to D^\circ D^- \\ &\to D^\circ \bar{D}^\circ \pi^- \\ &\to D^+ D^- \pi^- \\ &\to D^\circ D^- \pi^\circ . \end{aligned}$$

As stated in the introduction, we impose this prejudice by demanding a restricted mass proton recoil. The details of how this works is covered in Appendix C.

This fundamental choice then determines other basic parameters of the experiment. In particular, it determines the target and the minimum practical beam intensity. The first must be liquid hydrogen, the second must be 10^6 per pulse. The relevant properties of the recoil proton trigger are given by:

(a) Δ^2 range $\sim 0.05 - 0.40$ GeV^2; this range includes about 60% of the diffractive cross section ($\Delta^2 \equiv |t|$) .

(b) Azimuthal acceptance $\sim$ 30% ($\pm$ 27° in each of the arms) giving an overall acceptance of 18%.

(c) $\int_{12.5}^{40} \frac{d\sigma}{dM^2} dM^2 = 1.2$ mb. (at $p_{inc} = 150$ GeV, slightly less at higher momenta.)

The acceptance reduces the basic trigger cross-section to $\sim .22$ mb, and for our intended target which is 40 cm long, this means a basic recoil proton arm trigger rate of 400 clean diffractive triggers per burst (the raw trigger rate including bad triggers and triggers outside the desired M_X^2 range will be $\sim$ 50% higher).

We cannot, of course, actually take triggers at this rate (the deadtime of the spectromer is $\sim$ 0.03 seconds). The additional trigger requirements described below will reduce the basic trigger rate.

(a) <u>$(p \cdot \mu)$ trigger</u>:

This trigger requires (in addition to the basic proton-recoil trigger) the detection of a muon of either sign, behind the Fe hadron absorber (see Appendix D). The acceptance for μ's from $D \to \mu\nu X$ decays and for background decay in flight μ's ($\pi \to \mu\nu$, $K \to \mu\nu$) depends in detail on the size and shape of the hodoscope used (this can be adjusted to discriminate against lower momentum μ's and also to discriminate against μ's with low vertical momentum). For a typical choice and for $p_{inc} = 150$ GeV the relevant parameters are:

Average Probability of Recording μ from D-decay: $\sim 1/3$

Probability of triggering on a μ from $\pi \to \mu\nu$ decay:

$\sim 5\text{x}10^{-3}$ (per diffractive interaction).

(b) <u>$(p \cdot \Delta n = 2)$ trigger</u>:

For this trigger (in addition to the basic proton recoil trigger), we make a further requirement designed to enhance the probability that the event has one (or two) K_S^o decays. The requirement is that the pulse-height in a counter $\sim$ 2.25 meters downstream of the target minus the pulse-height in a counter just downstream of the target exceeds a threshold set to correspond to two additional particles in the downstream counter. The performance of such a trigger was tested in the April 1975 P-369 test, and is described in detail in Appendices A and F.

Based on the results of the Spring P-369 test, we assume the following performance:

(α) The "$\Delta n = 2$" requirement suppresses the trigger rate by a factor of ~ 6.

(β) The pulse height difference threshold is set so that the probability that a 1 K_S° event (2 extra tracks) exceeds the threshold is 50%.

(γ) The probability that a 2 K_S° event exceeds threshold is $\sim 100\%$.

These then, are the two triggers that we presently consider most promising. They are both based upon the recoil proton trigger which limits us to diffractive type production. This choice is governed by the fundamental consideration of the search, namely, that we be able to reconstruct the complicated multiparticle decay states that we expect for the charmed meson. To reconstruct these states with acceptable efficiency and mass resolution, we constrain them via the recoil proton trigger to move with high laboratory momentum into the CCM spectrometer. This spectrometer has good acceptance at high momentum and small angles, so we benefit by the kinematic bias. In order to remind the reader of the salient points, we briefly describe the properties of the spectrometer with emphasis on the relationship to this experiment:

(a) <u>Momentum acceptance</u>

In the present spectrometer configuration tracks are detected upstream of the magnet only by 4x and 4y MWPC's [1m x 1m]. This prevents space reconstruction of tracks unless the tracks are also seen by the spark chambers downstream of the magnet. As a result, low-momentum tracks cannot be measured at all, at B = 12.5 kg, the cut-off is at about 5 GeV. In addition, one has to rely on extrapolation of the track through the magnet to "match" x and y upstream projections. We propose to remedy this problem by adding 3 or 4 x' planes ($\theta_{x'}$ at say 20° from the vertical) and 3 or 4 y' planes upstream of the magnet. [The MWPC's to be used are under construction and are expected to be ready in February 1976]. This will allow reconstruction of upstream tracks without reference to the downstream chambers. In addition we propose to add 3 or 4 MWP chambers in the upstream half of the magnet. The chambers will permit the measurement of low momentum tracks. This will allow detection and measurement of all tracks (within $\sim \pm 90$ mr) down to 1 or 1.5 GeV.

(b) K°_S Detection

As in the P-369 test we intend to have a (fiducial) decay region of about 200 cm between the target and the first MWPC plane. The acceptance for K°_S, however, will be dramatically improved over what we had in the test as we discuss next. Under the test conditions, (which did not use a proton recoil trigger) the K° spectrum was such that only about 42% of all K°_S decays occurred in the fiducial volume. In the presently proposed experiment K°'s are produced in a cluster M_X^- of limited mass moving in the laboratory with a total forward momentum about equal to the beam momentum. At 150 GeV $\sim$ 62% of all $K^\circ_S \to \pi^+\pi^-$ decays will occur in the fiducial volume (equivalent to 21% of all K° or $\bar{K}^\circ$'s decaying in the fiducial volume). In the test the π^+ and π^- tracks from a K°_S decay were accepted by the spectrometer 25% of the time [since only tracks above 5 GeV could be detected, there was no acceptance for $p_K < 10$ GeV]. In the proposed experiment because of the diffractive origin of the K's and because of the additional PWC planes, we estimate an acceptance of $\sim$ 93%. We are, therefore, able to detect $\sim$ 20% of all K°'s and $\bar{K}^\circ$'s (we detected $\sim$ 3.5% in the test).

(c) $K^\pm$ Detection

The Oxford group has built and installed a 20-cell Cerenkov counter, and expects to test its properties during the coming weeks. Until tests are completed we will not know over what range of momenta it will achieve π, K discrimination. From the design of the counter we believe it should discriminate between π's and K's in the range p = 10-25 GeV. (See Appendix I.) What fraction of $K^\pm$ are identified then depends on the fraction of $K^\pm$ present between these limits. For $p_{inc} = 150$ GeV and $D \to K\pi\pi$ the fraction is $\sim$ 35% (it is lower for $K\pi$, and higher for $K3\pi$).

In the remainder of this proposal we will assume that 30% of charged K's will be identified.

Our plan, therefore, is to proceed in a somewhat different manner than was advanced in the preliminary proposal. We continue to use the CCM spectrometer, but upgrade significantly the capability for measuring low momenta with new MWPC's in the gap. We add a recoil proton trigger and a liquid hydrogen target. We retain our patented K_S^o (Λn) trigger and add a muon trigger. These components will be combined to yield what we believe is the most sensitive search experiment which can be done in strong interactions with any existing or presently expected equipment. To accomplish our goal, we will need a total pion flux of 2×10^{11} at 150 GeV/c.

We now proceed to a rather detailed calculation of the rates, yields and backgrounds.

V. Trigger, Rates and Background

The possible range of estimates for $D\bar{D}$ production, for their branching ratios first into leptonic and non-leptonic modes and further into specific final states is staggering.[8] It would serve no particular purpose to explore all of these in detail and no purpose to present all the details here. The explicit assumptions made in arriving at numerical results are the following:

(a) We assume that 10^{-3} of our diffractive events produce $D\bar{D}$. In terms of cross-sections it means that we are assuming a cross section for diffractive production of $D\bar{D}$ of 1.2 mb x 10^{-3} = 1.2μb

(b) We assume branching ratios between leptonic and non-leptonic modes of

$D \to \mu\nu$ + anything	10%
$D \to e\nu$ + anything	10%
$D \to$ hadrons	80%

We ignore the detail that the branching ratios may be (probably are) different for D° and D^+. For a charged pion multiplicity of 4.4 at 150 GeV (see Appendix D), (a) and (b) together imply that 45% of prompt μ's come from $D\bar{D}$ decay (if $\mu^{\pm}_{prompt}/\pi^{\pm} = 10^{-4}$).

(c) Where it is relevant (i.e. when we look for K's coming from D decay) we explicitly assume the theoretical prediction that K should occur in (almost) all hadronic and semileptonic D-decays; we also assume that pure leptonic decays are severely suppressed relative to the semileptonic modes.[8]

(d) We assume that 1/3 of the hadronic decay modes of the D's involve no π°, while 2/3 involve one or more π°'s. This fraction depends on the detailed dynamics and the number of π's produced with the K's and the isospins of the π combinations. The fraction 1/3 comes from listing all K,nπ modes, guessing the probability of various n_π, and assigning π charges. We have used weights of 20% for $n_\pi = 1$, 40% for $n_\pi = 2$ and 40% for $n_\pi = 3$. For these K,nπ modes we listed all allowed charged and neutral combinations and gave each equal weight. One gets substantially the same fraction by using Clebsh-Gordon coefficients for reasonable channels. We note that we are rather more conservative than G.L.R. (see Table IV, Ref. 8).

The proposed $(p \cdot \mu)$ trigger consists of a coincidence between the proton recoil detector and a μ detected in the μ detector hodoscopes. The number of counts in the proton recoil detector is expected to be 600 counts/burst of which 400 events correspond to clean diffractive interactions. The total number of diffractive interactions which we consider is then

$$8 \cdot 10^7 \text{ diffractive interactions} = \frac{400 \text{ interactions}}{\text{burst}} \times 2\text{x}10^5 \text{ bursts}$$

This is the number of interactons which were used to obtain the $(p \cdot \mu)$ trigger rates and signal and background estimates.

The $(p \cdot \mu)$ trigger rate is dominated by π-μ and K-μ decays and this number has been computed for the $\pi^- p$ interactions at 150 GeV/c in Appendix D. The fraction of diffractive interactions leading to a $(p \cdot \mu)$ trigger is found to be $5\text{x}10^{-3}$ in Appendix D with the restrictions on the μ ($|x| < 1.5$ and $|y/x| > .24$). This leads to a $(p \cdot \mu)$ trigger rate of 3/burst with very small loss (8%) due to deadtime.

The estimated signal rates are now obtained using our best guesses for $D\bar{D}$ production and decay. We will be interested in several estimates within four prong and six prong topologies. In particular, we consider the possibilities of dominant π decay modes for the D's, dominant K decay modes for the D's, and dominant K decay modes for the D's with further identification of charged K's using Cerenkov counters or neutral K identification by detection of $K^\circ_S \to \pi^+\pi^-$.

First we assume that 10^{-3} of the diffractive events lead to a $D\bar{D}$ final state or that $10^{-3} \times 8 \cdot 10^7 = 80{,}000$ $D\bar{D}$ events are produced. The μ trigger now requires the D (or $\bar{D}$) to undergo $\mu + \nu + X$ decay while the $\bar{D}$ (or D) must decay into hadrons to be measured in the spectrometer. Therefore

$$2 \times .1 \times .8 = 16\% \qquad \text{or } 12{,}800 \text{ events}$$

will be useful. We assume that 1/3 of the μ's from the D's are detected as shown in Appendix D. We are left with 4,300 events with hadron decay and satisfying the $(p \cdot \mu)$ trigger. Only hadronic events without π°s are useful for determination of the D mass so we lose 2/3 of these events and are left with 1420 events. We estimate (based on tracking Monte Carlo simulated D decays through the detection system) that 80% of these decays or 1140 events will be accepted and reconstructed. We note if π decay modes dominate then this is the expected signal in the charged track topologies. (Below we will calculate the number in four prongs and six prongs). If the present theories linking charm with strangeness in D decay are correct, K decay modes will dominate. Then half of these events, or 570, would be associated with charged K, and we estimate 30% of the charged decays can be identified by the Cerenkov counters (based on the number of charged K's between 10 and 25 GeV in the Monte Carlo simulation of D decays). In turn, 20% of the K°'s can be detected so we will have 285 events with K° or charged K identified. We have examined the topologies among the reactions $\pi p \rightarrow pD\bar{D}$ and $\pi p \rightarrow pD\bar{D}\pi$ with μ decays and estimate that 80% of the events would be in the 4 or 6 prong topologies, 20% in the 8 prong topologies. For simplicity we use the same 80% factor for K°'s and multi π events to obtain the number of signal events given in Table V - 1

The next question concerns the background associated with the $(p \cdot \mu)$ trigger from (multi π) or (K, $m\pi$) mass combinations appearing in the mass spectrum near the D mass. We estimate a mass resolution (standard deviation) of 10-15 MeV (for M = 2 GeV, 2-4 body decay). The relevant background is therefore the number of combinations of tracks (and permutations of masses for unidentified $K^{\pm}$) in a 25 MeV bin at the D mass (taken to be 2 GeV). We have obtained these mass combinations from bubble chamber events as described in Appendix G for charged (multi π) and charged ($K^{\pm}$, $m\pi$) topologies.

For the charged ($K^{\pm}$,$m\pi$) topologies we have obtained two backgrounds in Appendix G all charged ($K^{\pm}$,$m\pi$) combinations which assume no $K^{\pm}$ identification and only those charged ($K^{\pm}$,$m\pi$) combinations for which the charged $K^{\pm}$ can be identified by the Cerenkov counter. To the charged ($K^{\pm}$,$m\pi$) background with $K^{\pm}$ identified we have added our estimate of background for (K°,$m\pi$) with K° identified. For simplicity we assumed the same ratio 2/3 for (K°,$m\pi$)/($K^{\pm}$,$m\pi$) in the background which we used for the signal above. Therefore the number ($K^{\pm}$,$m\pi$) combinations with $K^{\pm}$ identified found in Appendix G were multiplied by 5/3 to obtain the background estimate for (K,$m\pi$) background with K identified.

The summary of our estimates of signal events and background combinations is given in Table V-1. As explained above these numbers correspond to $8\cdot10^{7}$ diffractive interactions or $4\cdot10^{5}$ ($p\cdot\mu$) triggers.

Table V-1
Signal and Background for ($p\cdot\mu$) trigger
$8\cdot10^{7}$ diffractive interactions
($4\cdot10^{5}$ $p\cdot\mu$ triggers)

case	signal	background	significance
multi π 4 and 6 prongs	912	5381	12σ
$K^{\pm}$, $m\pi$ 4 and 6 prongs no identification	456	8,126	5σ
K, $m\pi$ 4 and 6 prongs K, identification	228	353	12σ

Our other favored trigger is the p $\cdot$ $\Delta n = 2$ coincidence. In this case, the p $\cdot$ $\Delta n = 2$ coincidence rate will saturate the data taking capability. The raw rate of proton recoil triggers ($\sim$ 600/burst) is reduced by the $\Delta n = 2$ requirement by a factor of 6 to $\sim$ 100 raw triggers/burst. For these 100 raw triggers per 1 sec burst we will have a reduction of 1/4 due to the deadtime of 30 msec. This leaves 25 (p $\cdot$ $\Delta n = 2$) actual triggers per burst. With $2 \cdot 10^5$ bursts this yields $3.3 \cdot 10^6$ clean diffractive triggers with $\Delta n = 2$. This sample will contain about 400,000 kaons including approximately 80,000 $K\bar{K}$ pairs. This represents an enhancement of a factor of 1.7 in K yield (2.8 for the $K\bar{K}$ yield) due to the $\Delta n = 2$ requirement. These numbers were obtained in calculations very similar to those detailed in Appendix A and are partially justified by the analysis of the data obtained in P-369.

In some fraction of the events we will have two K's, i.e. $K_S^o + K_S^o$ or $K_S^o + K^\pm$. For $K\bar{K}$ events we can form D and $\bar{D}$ combinations and calculate both masses. We therefore expect to find a much smaller signal superposed on a greatly reduced background of one bin in a two dimensional scatter plot for M_D vs. $M_{\bar{D}}$. Our estimates of signal and background are given in Table V-2

Table V-2

Class	Signal	Background	Significance
1 K_S^o	530 events	10,000 events	5.3 σ
2 K_S^o or 1 K_S^o + identified $K^\pm$	90 events	40 events	14 σ

In our view the estimates of signal and background rates for either trigger justify a conclusion that the proposed experiment constitutes a search for charmed particles at an interesting level of sensitivity. In addition to the significance level quoted, it is presumably quite obvious that there are several games one can play in case a narrow resonance is observed to decide whether or not it is related to the production of charmed particles. Apart from a direct observation of pairs of narrow resonances there are indirect arguments based on one or more of the following:

a) For the μ trigger, there should be a signal for $D^+ \rightarrow$ hadrons with μ^- and $D^- \rightarrow$ hadrons with μ^+ but not for like charges.

b) For the μ trigger with identified K's, there should be a signal for $K^+\mu^+$, $K^-\mu^-$, but not for unlike charges.

c) $D\bar{D}$ events in the reaction $\pi^- p \rightarrow pX^-$ with $X^- \rightarrow DY$ (where the D is reconstructed from hadron decay) should show the threshold effects that $M_{X^-} > 2m_D$ and $M_Y > m_D$.

If the branching ratios we have assumed above (10% $D \rightarrow \mu\nu X$, 80% $D \rightarrow$ hadrons) are correct, the μ-trigger seems more attractive for a first search, particularly if it turns out that the assumption of K-dominance is incorrect. In addition, fewer events have to be reconstructed.

There are nevertheless two circumstances which might make the "$\Delta n = 2$" the trigger of choice:

(a) If it should turn out that the branching ratio for $D \rightarrow \mu\nu X$.. is very small, in spite of the suggestive results of the $\gamma \rightarrow$ dimuon experiment.

(b) If it turns out that we cannot handle a flux of 10^6 π's per burst, in the "$\Delta n = 2$" trigger the flux can be reduced by a factor of 2 with only a 20% loss in event rate.

We would like therefore to keep our choice open. We intend to develop and test the hardware for both triggers, and maintain an open mind toward other possible approaches such as the two muon trigger outlined in Appendix E. We feel that the exact trigger to "go with" for the bulk of the data will have to be determined by more work, but we are betting at present on the two concepts above $(p \cdot \mu)$ and $(p \cdot \Delta n = 2)$. We now describe our requirements and the schedule we can meet, if approved.

VI. Schedule, Personnel, Apparatus and Beam Requirements.

In order to carry out the experiment outlined above, we request the use of the Chicago Cyclotron Magnet Spectrometer with the associated Sigma-3 computer as a data acquisition system. The present group is augmented from the original P-369 experimenters by the addition of the Oxford group, and we are confident that we can continue to operate the CCM facility in an effective manner. The part of the spectrometer supplied by the University of Chicago was operated successfully in the spring run through the helpful advice and aid of University of Chicago physicists, and we expect this cooperation to continue. Instead of reviewing the entire apparatus, we state that we will use the spectrometer essentially as it is to be used by E-398 in Spring 1976, and elaborate only on the changes which will be necessary to accomplish the present experiment.

1. Proton Recoil Spectrometer:

We plan to add a new layer of scintillation trigger counters to the existing recoil arms. These counters are narrower and viewed by PMT's at each end to provide good timing for the recoil proton trigger. The present counters are also used (in the latched mode) to provide additional analysis information. The new counters cover areas of 3 feet by 6 feet on each side of the beam (12 elements total). They already exist at Illinois and are being refitted and tested at present. In addition to the new counters, we will build two new proportional wire chambers at Illinois and install them immediately outside the target vessel on each side. They are also used in the recoil proton trigger, in this case to supply an angle requirement on the recoil and help suppress the accidental coincidence rate in the recoil arm. Each PWC will measure horizontal and vertical coordinates. The electronics for the PWC's and their inclusion in the trigger will be supplied by Illinois. We will also use some or all of the present magnetostrictive spark chambers on the recoil arms. The cylindrical drift chambers being planned for the E-98 run must be removed as they are much too thick for the present purposes. We will also install He bags on each side between the PWC and the spark chambers to limit multiple scattering.

2. Liquid Hydrogen Targetr

Our recoil proton trigger cannot be used with the very large target cup and vacuum vessel used by the muon group. We therefore request FNAL to supply a new target cup and vacuum vessel as described in Appendix H. The new cup and jacket should be technically simple to make and will attach to the present reservoir and refrigerator. We will consult with appropriate FNAL technicians on the exact requirements at a later time.

3. Beam and Running Time Requirements:

300

This experiment requires 2×10^{11} negative pions at a nominal beam energy of 150 GeV. We desire the beam to be supplied at an intensity of 10^6 per pulse, for a total of 2×10^4 pulses (or 670 effective beam hours at a presumed cycle rate of 300 pulses per hour). This is the maximum beam rate that we feel comfortable with, taking into account our experience with the spring test run and the E-398 experience. This intensity should require about 1.6×10^{12} protons per pulse at 300 or 400 GeV primary energy if the triplet load is used as a beam forming element.

700 hr

We also require a good beam focus at the target and therefore request vacuum at every point along the transport where practical, and helium bags where no vacuum can be maintained. We also hope that a number of beam counters presently used to tune the beam be replaced by SWIC's or something of comparable thickness so that the beam passes through less material. We achieved a beam spot size of 3 cm diameter in our test run with lots of air and many unnecessary counters in the beam. We calculate that the spot size can be reduced to less than 1 cm diameter with proper care. The spot size constraint comes from the recoil proton trigger requirements.

4. Computer Requirements:

We request use of the Sigma 3 computer presently attached to the CCM spectrometer. We will arrange with the University of Chicago for maintainance during our run in the same manner as for the spring test run. We also request a BISON link to the CDC-6600 if it is installed in the neutrino lab by the time we are to run. We will also require some fast turn around off-line computing time on the CDC 6600. A nominal figure of one hour per day seems consistent with our past experience. The bulk of the off-line analysis will be supplied by Oxford, using the Rutherford IBM 370-195 which has proved its worth in the muon analysis. We will inherit all the software developed for that experiment in addition to a large program developed at Illinois for analysis of the test run, and expect a significantly shorter data analysis interval after the run is over. It is hard to over-emphasize the importance of having this software already in working order.

5. Electronics Requirements:

We request use of all the electronic equipment associated with the existing CCM spectrometer. We will have to add a modest amount of additional equipment from PREP to use with the recoil proton arm (in addition to the specialized equipment provided by Illinois). Specifically, we need the following items:

30 channels 2-fold coincidence (Lecroy 365AL or equivalent)

30 channels discriminators (Lecroy 621AL or equivalent)

32 channels time-digital converter (Lecroy 2228)

32 channels analog-digital pulse height converters (Lecroy 2248)

12 channels linear amplifiers (Lecroy 335L or equivalent)

6. Miscellaneous Requirements:

We expect to request use of the muon hodoscope supplied by E-331. We will also use the recently installed multicell Cerenkov counter for K-π discrimination. We will also expect to use the additional .8 x .8MPWC chambers to be installed by Illinois for the upcoming muon run. We anticipate no problems with these items which will be in place and working by spring 1976.

The experimenters proposing this experiment constitute a large and sufficient staff to run the spectrometer and analyze the data. We are intending to make this our principal research effort in 1976-77. The sub-group associated with

E-98 will see that analysis goes forward on the muon data (the bulk data processing is largely automated by now) while the present experiment is set up and run. Then, the charm bulk data processing can begin, followed by detailed analysis of the reconstructed tracks on smaller computers at Illinois and Harvard as well as at Oxford. This is essentially how the process worked for analysis of the E-98 and P-369 test data which followed in sequence in a similar way. The main difference was that the P-369 test data was sufficiently limited that we ran even the bulk processing on the Illinois PDP-10. We anticipate using the 195 for this job with the larger data set in the present experiment.

All the new equipment to be built (principally the recoil proton chambers, counters and electronics) will be completed and ready to install by May 15, 1976. We are hoping that the laboratory will approve our run to commence immediately after the P-398 muon run in Spring 1976. We will be prepared and anxious to begin at that time.

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APPENDIX A

TRIGGER AND RECONSTRUCTION RATES

FROM THE P369 TEST RUN

I. Definitions

In April 1975 a trigger study (FNAL Proposal P369) was performed in the muon laboratory at Fermilab. Since the details of the triggers implemented were slightly different from those specified in the proposal, they will be discussed briefly here.

Fig. A1 is a sketch of the target area and the associated trigger counters. The hadron beam, already tagged by a telescope of scintillation counters, was defined by steering it through a 7/8 inch hole in a veto counter just upstream of the target. Approximately 1/2 of the hadrons arriving at the muon lab were vetoed by this requirement. The beam so defined varied from 10K to 70K per pulse during the test.

The target was a 1.6 cm lucite block giving an interaction probability of 3%. Pulse heights somewhat above twice minimum ionizing in scintillation counters T_A and T_B signaled an interaction.

$$I \equiv (\text{Beam})\cdot(T_A > {\text{some} \atop \text{minimum}})\cdot(T_B > {\text{some} \atop \text{minimum}})$$

The basic trigger involved an attempt to isolate neutral particle decays into charged particles from amongst the sea of "ordinary" hadronic final states. In particular, events with two K_S^o decays were desired. Signals from T_B and T_C were integrated and compared on-line. The pulse height from T_C was required to exceed that from T_B by some multiple, Δn, of the mean single particle pulse height, the ideal $K_S^oK_S^o$ signature corresponding to $\Delta n = 4.0$.

$$\underset{\text{requirement}}{\Delta n} \equiv (T_C - T_B) \geq \Delta n \times ({\text{single} \atop \text{particle}})$$

As the charged multiplicity of the primary interaction rises it becomes increasingly difficult to recognize reliably the $\Delta n = 4.0$ condition. Accordingly, the primary charged multiplicity was limited by imposing maximum pulse height restrictions (in addition to the minimum levels already enforced) on T_A and T_B. This

TABLE A1 RESULTS

TRIGGER MODE	EVENTS	RECONSTRUCTED SINGLE K_s	RECONSTRUCTED DOUBLE K_s	$\frac{\text{EVENTS}}{\text{BEAM}}$	$\frac{(\text{RECONSTRUCTED SINGLE } K_s)}{\text{BEAM}}$	$\frac{(\text{RECONSTRUCTED SINGLE } K_s)}{\text{TRIGGER}}$
I	6.5K			3.2×10^{-2}		
I_H				7.6×10^{-3}		
I. $(\Delta H \geq 5)$	5.9K	49	1	6.5×10^{-3}	$(41 \pm 6)\times10^{-6}$	0.8%
$I_H \cdot (\Delta N \geq 3.2)$	3.7K	94	1	5.4×10^{-4}	$(12 \pm 1)\times10^{-6}$	2.5%
$I_H \cdot (\Delta N \geq 3.5)$	4.8K	95	1	3.6×10^{-4}	$(7.7 \pm .8)\times10^{-6}$	2.0%
$I_H \cdot (\Delta N \geq 4.0)$				2.6×10^{-4}		
$I_H \cdot (\Delta N \geq 5.5)$	3.7K	59	1	1.4×10^{-4}	$(1.3 \pm .2)\times10^{-6}$	1.6%
$I.(\Delta N \geq 4.0)\cdot(\Delta H \geq 5)$	7.0K	99	1	5.6×10^{-4}	$(6.9 \pm .7)\times10^{-6}$	1.4%
$I_H \cdot (\Delta N \geq 4.0)\cdot(\Delta H \geq 5)$	4.8K	152	2	1.0×10^{-4}	$(2.2 \pm .2)\times10^{-6}$	3.1%
ALL TRIGGERS	36.4K	584	7			

gave I_H – the "H" denoting the veto on high pulse heights.

$$I_H \equiv I \; (T_A < \text{some maximum}) \cdot (T_B < \text{some maximum})$$

As implemented during the test, this restricted the trigger primarily to events with three or four prongs at the primary vertex.

Unless a particle's momentum could be reconstructed by detecting it downstream of the cyclotron magnet as well as upstream, its usefulness was minimal. Accordingly, events with small multiplicity downstream of the cyclotron magnet were suppressed by requiring 5 or more elements of a downstream scintillation counter hodoscope to latch. The hodoscope used was the E-98 "H" counter array.

$$\underset{\text{requirement}}{\Delta H} \quad (\geq \begin{matrix}\text{5 H-counter}\\ \text{elements set}\end{matrix}).$$

Data were recorded using many different triggers constructed from this set of four building blocks. In this appendix a preliminary analysis of these data is presented. After a discussion of the theory of this trigger, the results are compared in some detail with the stated objectives of P369. Some conclusions are drawn but a discussion of the resulting trigger modifications is left to the body of this new proposal.

II. P369 Trigger Study Results

All rates were quite stable and reproducible during the test. Certain of the data, however, did suffer from apparatus malfunctions which have prevented a complete analysis of some trigger modes at this stage of the data analysis. The following, regrettably incomplete, table A1 presents the results of a preliminary study of the data.

Before discussing these rates, we present, as an indication of event quality, Fig. A2. These two histograms display the reconstructed mass of the K°_S and the Λ°. The resolution is excellent - 15 MeV full width at half-maximum for the K°_S; 10 MeV for the Λ°. The background is very small, less than 5% of the K°_S with the mass cuts indicated. This event quality is obtainable principally because the decay vertex can be isolated very cleanly from the primary interaction vertex. The neutral V can be located to within 2 mm in directions transverse to the beam and to within 2 cm in the longitudinal direction.

Fig. A3 presents effective mass plots for various combinations of K_S^o's and hadrons, namely, $m(K_S^o\pi)^{+/-}$, $m(K_S^o\pi\pi)^{++/--}$, and $m(K_S^o\pi^+\pi^-)$. Finally, Fig. A4 display- the energy spectrum of reconstructed K_S^o's.

In summary, from this table we see that

1. The number of reconstructed single K_S^o events per trigger is small, $\sim$ 2%. The number of events with two reconstructed K_S^o's is two orders of magnitude lower.

2. The ΔN requirement does enhance the fraction of observed strange particle events per trigger by about a factor of 3 over a simple interaction trigger.

3. The ΔH requirement does lead to an increase in the reconstruction rate by about a factor of 2.

4. The energy distribution of reconstructed K_S^o's has a sharp, low energy cut-off at about 15 GeV. This is the limit of the spectrometer's acceptance when the magnet is excited to 12.5 KG. Since the production of inclusive K_S^o's is strongly peaked near 4.5 GeV (at X = 0), most of the strange particle triggers did not enter our geometry.

III. Trigger Theory

a. Beam Composition

The beam consisted of 150 GeV positive hadrons. Since the Fermilab Cerenkov tagging system did not become operational until the last few days of the test, the beam particle was not identified for each event. Here it will be assumed that the beam was composed of 75% protons and 25% pions. Since $\sigma_{pp}/\sigma_{\pi p} \sim 8/5$, this beam contributes to the simple interaction trigger as follows:

probability of interaction having been pp	= 0.83
probability of interaction having been π^+p	= 0.17.

In the remainder of this section the major component, pp, will be discussed in detail.

b. Population of Strange Particle Channels

Interpolation of FNAL bubble chamber data yields the following estimates for neutral, strange particle production in ppp-scattering at 150 GeV. The yields per interaction[19]

$$\langle K_S^\circ \rangle = 0.130 \pm 0.014$$

$$\langle \Lambda^\circ \rangle = 0.110 \pm 0.014$$

$$\langle \bar{\Lambda}^\circ \rangle = 0.012 \pm 0.007$$

Since $\langle \bar{\Lambda}^\circ \rangle$ is so small, most of the $\langle \Lambda^\circ \rangle$ must come from $\langle K\Lambda^\circ \rangle$ channels. Subtracting the $\langle \Lambda\bar{\Lambda} \rangle$ component leaves

$$\langle K^\circ\Lambda^\circ \rangle + \langle K^+\Lambda^\circ \rangle = 0.098 \pm 0.016.$$

At 16 GeV[19] measurements exist (but for π^+p) which show

$$\sigma_{K^\circ\Lambda} = 0.36\text{mb}, \ \sigma_{K^+\Lambda} = 0.51 \text{ mb}$$

$$\sigma_{K^\circ\Sigma^\pm} = 0.25 \text{ mb}$$

Here the assumption is made that these ratios are maintained within 10% at 150 GeV. It is important that K^+ be larger than K° in order that the small excess of K^+ over K^- be explained.

This assignment "uses up" some 0.034 ± 0.005 K_S°'s per interaction. The remaining K_S°'s must originate in the $K\bar{K}$ channels. Here the assumption is made that all $K\bar{K}$ channels are equally populated. The final result for p-p interactions is given in Table A2.

Table A2 - Strange Particle Channel Populations

Channel	Probability/Interaction
$\langle K^\circ\bar{K}^\circ \rangle = \langle K^+K^- \rangle$	0.048 ± 0.008
$\langle K^\circ K^- \rangle + \langle \bar{K}^\circ K^+ \rangle$	0.096 ± 0.015
$\langle K^\circ\Lambda \rangle$	0.041 ± 0.011
$\langle K^+\Lambda \rangle$	0.057 ± 0.015
$\langle K^\circ\Sigma^- \rangle + \langle K^\circ\Sigma^+ \rangle$	0.028 ± 0.008
$\langle \Lambda\bar{\Lambda} \rangle$	0.012 ± 0.007

c. Decay and Trigger Factors

The ΔN trigger responds only to those decays occurring in our fiducial region, in the two meters between counters T_B and T_C. Using the momentum distribution of inclusive K°_S's and Λ's from FNAL bubble chamber data, the probability of decay within this region can be calculated.

$$\text{Mean Probability that a } K^\circ \text{ or } (\bar{K}^\circ) \text{ decays to } \pi^+\pi^- \text{ in fid. region} = \underbrace{(\tfrac{1}{2}\ \tfrac{2}{3})}_{\text{B.R.}}\underbrace{(0.42)}_{\text{Geometry and Momentum Spectrum}} = 0.14$$

$$\text{Mean Probability for } \Lambda \to \pi^- p \text{ in fid. region} = (\tfrac{2}{3})(0.37) = 0.23$$

A systematic uncertainty of 10% will be assigned to these numbers in the calculation presented here.

It is important to note that this factor of 0.4 in the K° decay factor was assumed to be 0.7 in the P369 proposal.

The following definitions are now made;

F_x = fraction of events with $N = 2$ which give a $\Delta N \geq X$ trigger.

f_x = fraction of events with $N = 4$ which give a $\Delta N \geq X$ trigger.

The trigger rates from the strange particle channels are presented in Table A3.

Table A3 - Strange Particle Contributions to the ΔN trigger per interaction

Channel	Contribution	Est. Systematic Uncertainty
$\langle K^\circ\bar{K}^\circ\rangle \to K_S K_S$	$f_x(0.94 \pm 0.14)\times10^{-3}$	20%
$\langle K^\circ\bar{K}^\circ\rangle \to K_S X$	$F_x(11.6 \pm 1.9)\times10^{-3}$	12%
$\langle \bar{K}^\circ K^+\rangle \to K_S X$, $\langle K^\circ K^-\rangle \to K_S X$	$F_x(13.4 \pm 2.1)\times10^{-3}$	10%
$\langle K^\circ\Lambda\rangle \to K_S \pi^- p$	$f_x(1.3 \pm 0.4)\times10^{-3}$	20%
$\langle K^\circ\Lambda\rangle \to \pi^- pX$	$F_x(8.1 \pm 2.1)\times10^{-3}$	12%
$\langle K^\circ\Lambda\rangle \to K_S X$	$F_x(4.4 \pm 1.2)\times10^{-3}$	13%
$\langle K^+\Lambda\rangle \to \pi^- pX$	$F_x(13.1 \pm 3.4)\times10^{-3}$	10%
$\langle K^\circ\Sigma^-\rangle \to K_S X$, $\langle K^\circ\Sigma^+\rangle \to K_S X$	$F_x(3.9 \pm 1.1)\times10^{-3}$	10%

This gives a total trigger rate due to strange particle channels of

$$f_x(2.2 \pm 0.4) \times 10^{-3} + F_x(54.5 \pm 5.2) \times 10^{-3}$$

plus 20% systematic uncertainty   plus ∿ 11% systematic uncertainty

An estimation of the effect of the pion component of the beam (which can not produce as many Λ's) only reduces these numbers to

$$f_x(2.0 \pm 0.4) \times 10^{-3} + F_x(51.0 \pm 5.0) \times 10^{-3}$$

d. Acceptance and Reconstruction Factors

In the test only particles which pass through the spark chambers downstream of the magnet could be accepted. The geometry of the spectrometer (with B = 12.5 KG) was such that particles (of moderate transverse momentum) were accepted only if their longitudinal momentum exceeded about 5 GeV.

Mean geometric acceptance for K_S decaying in fid. region = 0.25.

Furthermore, it is assumed here that

apparatus efficiency and reconstruction per particle = 0.93

This last number is assigned a systematic uncertainty of 5%. It has not been studied in greater detail for the test run.

Taking into account the fraction of pions present, one obtains the reconstruction rates per interaction displayed in Table 4.

Table A4 - Contributions to Reconstructed K_S^o's per interacton

Trigger	Detect	Prob/Inter	Est. Systematic Uncertainty
2 K_S^o	2 K_S^o	$f_x(4.6 \pm 0.7) \times 10^{-5}$	40%
2 K_S^o	1 K_S^o	$f_x(1.8 \pm 0.3) \times 10^{-4}$	32%
$K_S \Lambda$	1 K_S	$f_x(2.6 \pm 0.6) \times 10^{-4}$	30%
1 K_S	1 K_S	$F_x(7.2 \pm 0.6) \times 10^{-3}$	21%

IV. Comparison with Test Results

Table A5 - Double K_S^o Events

ΔN	2 K_S^o Expected	2 K_S^o Observed
3.2	$f_{3.2}(2.5 \pm 1.4)$	1
3.5	$f_{3.5}(4.2 \pm 2.5)$	1
4.0	$f_{4.0}(20 \pm 11)$	3
5.5	$f_{5.5}(16 \pm 9)$	1

Here the estimated systematic uncertainty is displayed. f_x was expected to be near one for low ΔN, near 0.6 for $\Delta N = 4$, and approaching zero for $\Delta N \sim 4$. Taking the optimistic view and using the lower estimates of the systematic uncertainties, one calculates the following values of f_x:

Table A6 - $f_{\Delta N}$

ΔN	$f_{\Delta N}$
3.2	~ 0.9
3.5	~ 0.6
4.0	~ 0.3
5.5	~ 0.1

The errors associated with $f_{\Delta N}$ are large since typically only one event is involved.

F_x cannot be estimated independently of f_x. Because f_x is so poorly determined by the 2 K_S^o data, we use here the "theoretical" values $f_{3.2} = 1.0$, $f_{3.5} = 0.9$, $f_{4.0} = 0.6$, and $f_{5.5} = 0.1$. Then,

Table A7 - Single K_S^o Events

ΔN	Single K_S^o's Expected	Single K_S^o's Observed
3.2	$F_{3.2}[(4.1 \pm 0.8)x10^2] + (23 \pm 9)$	94
3.5	$F_{3.5}[(6.8 \pm 1.4)x10^2] + (34 \pm 14)$	95
4.0	$F_{4.0}[(3.5 \pm 0.7)x10^3] + (111 \pm 44)$	152
5.5	$F_{5.5}[(2.6 \pm 0.5)x10^3] + (15 \pm 6)$	59

Here the indicated errors are dominated by the estimates of the systematic uncertainties. To be consistent with the previous estimation of f_x, the lower limits should be used again. This gives the values of F_x presented in Table A8.

Table A8 - $F_{\Delta N}$

ΔN	$F_{\Delta N}$
3.2	0.24 ± 0.06
3.5	0.13 ± 0.03
4.0	0.02 ± 0.01
5.5	0.02 ± 0.02

These errors do <u>not</u> include the estimate of the systematic uncertainty involved in the calculation.

V. Overall Trigger Rate

It is a bit difficult to make detailed comparisons between the overall trigger rate observed in the test and that postulated in the original proposal. The proposal was addressed almost solely to the ΔN requirement, while the test nearly always combined ΔN with I_H and/or ΔH requirements. However, some comparison will be attempted with numbers appropriate to ΔN = 3.5. The numbers presented in Table A9 are normalized to 1 beam particle incident.

Table A9 - Total Trigger Rates

Trigger Source	Proposal	Est. from Test	Comments
$K^o_S K^o_S$	$1.6\text{x}10^{-4}$	$\sim 0.5\text{x}10^{-4}$	Mostly due to poor estimates of K^o_S momentum distribution
Other strange particle channels	$6.4\text{x}10^{-4}$	$\sim 1.4\text{x}10^{-4}$	Same as above
Secondary Interactions	$1.7\text{x}10^{-4}$	$\sim 3.0\text{x}10^{-4}$	
Other		$\sim 5 \text{ x } 10^{-4}$	Empty target rate (see Below)
Totals	$9.7\text{x}10^{-4}$	$\sim 10\text{x}10^{-4}$	Agreement of total rates completely accidental

During the test, the ΔN trigger was observed to have a large (30 to 50%) component which was present with the target removed. Off-line this large source of triggers was traced to the following problem. The "hole" in the veto counter (which was covered with several layers of black tape) was able to see some small part of T_C directly. An interaction in this tape, although rare, would not be vetoed, yet could easily fake the ΔN requirement because of the bad geometry. Clearly, this is correctable and would have reduced the overall trigger rate by a factor of 1.5 to 2.0 with no loss of good events.

VI. Conclusions.

1. The performance of the ΔN trigger requirement is understandable. The suppression of single V°'s over double V°'s may have been worse than expected by perhaps a factor of two.
2. The $K_S K_S$ trigger rate was overestimated by about a factor of 3 in the proposal.
3. Aside from a freak geometry problem, the secondary interaction probability was close to that calculated.
4. Since the misestimation of the inclusive K_S momentum spectrum affects the background, $\Delta N = 2$ triggers, as well as the 2 K_S triggers, its effect on the fractional trigger rate is lessened. Removing from consideration the triggers due to bad geometry, we infer that (2 K_S triggers)/(all triggers) ~ 0.1 at $\Delta N = 3.5$. This factor was estimated to be 0.2 in the proposal. The effect of the misestimation upon the reconstruction rate, however, cannot be lessened by any such arguments. The changes in the current proposal are directed primarily toward boosting this reconstruction rate with new trigger concepts and additional apparatus.

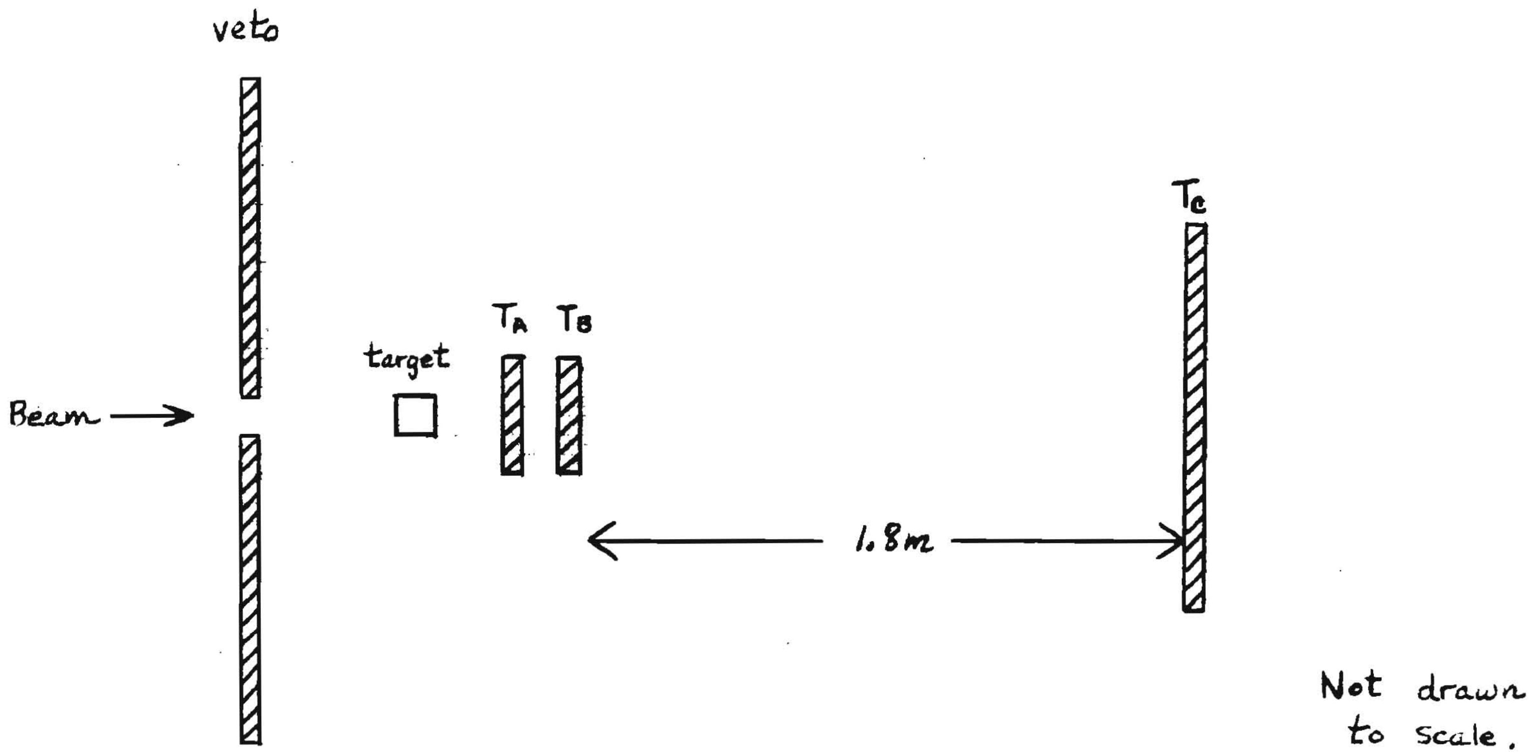
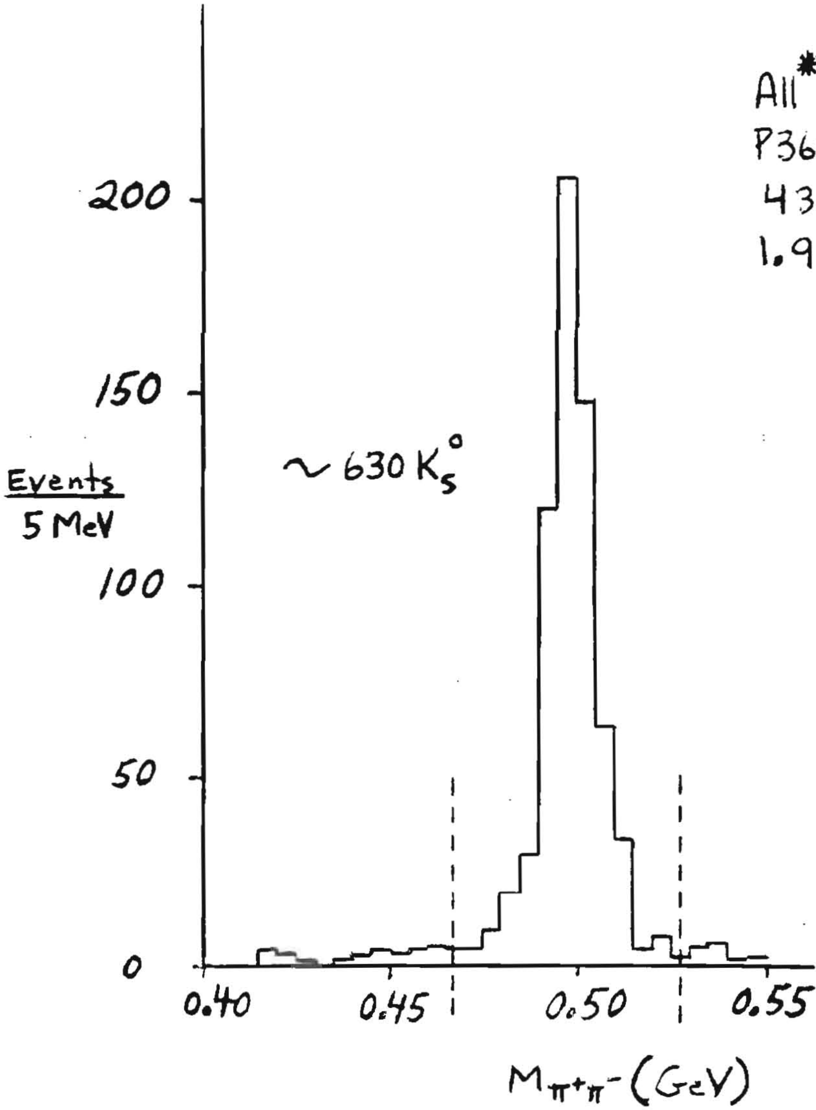


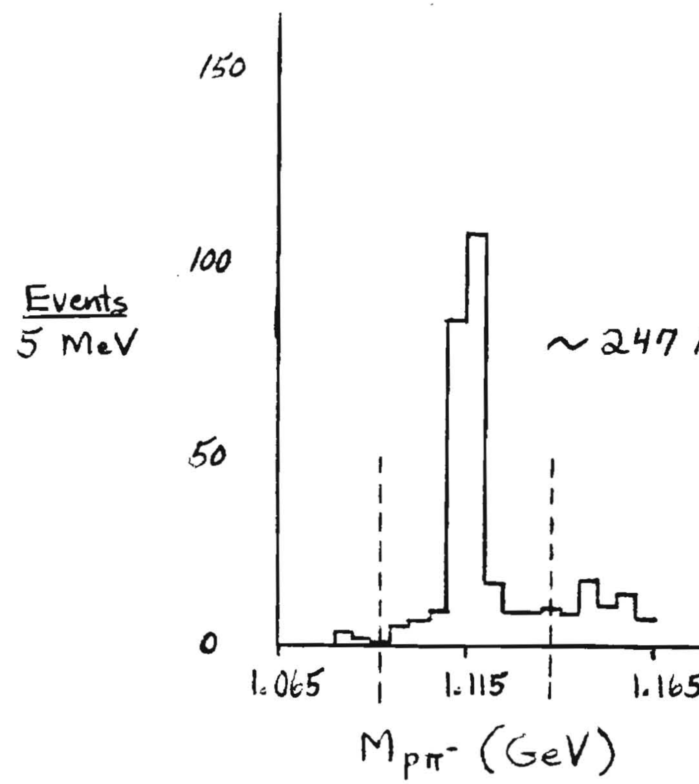
Figure A1. P369 Trigger Geometry

FIGURE A2

K_S^0, Λ^0 Mass Distributions

All* K_S^0 and Λ^0 from the P369 trigger study.
43.8 K triggers of all types
1.9×10^8 hadrons incident





* There are, in addition, ~120 K_S^0 which are less clean. Signal/background only ~ 3/1.

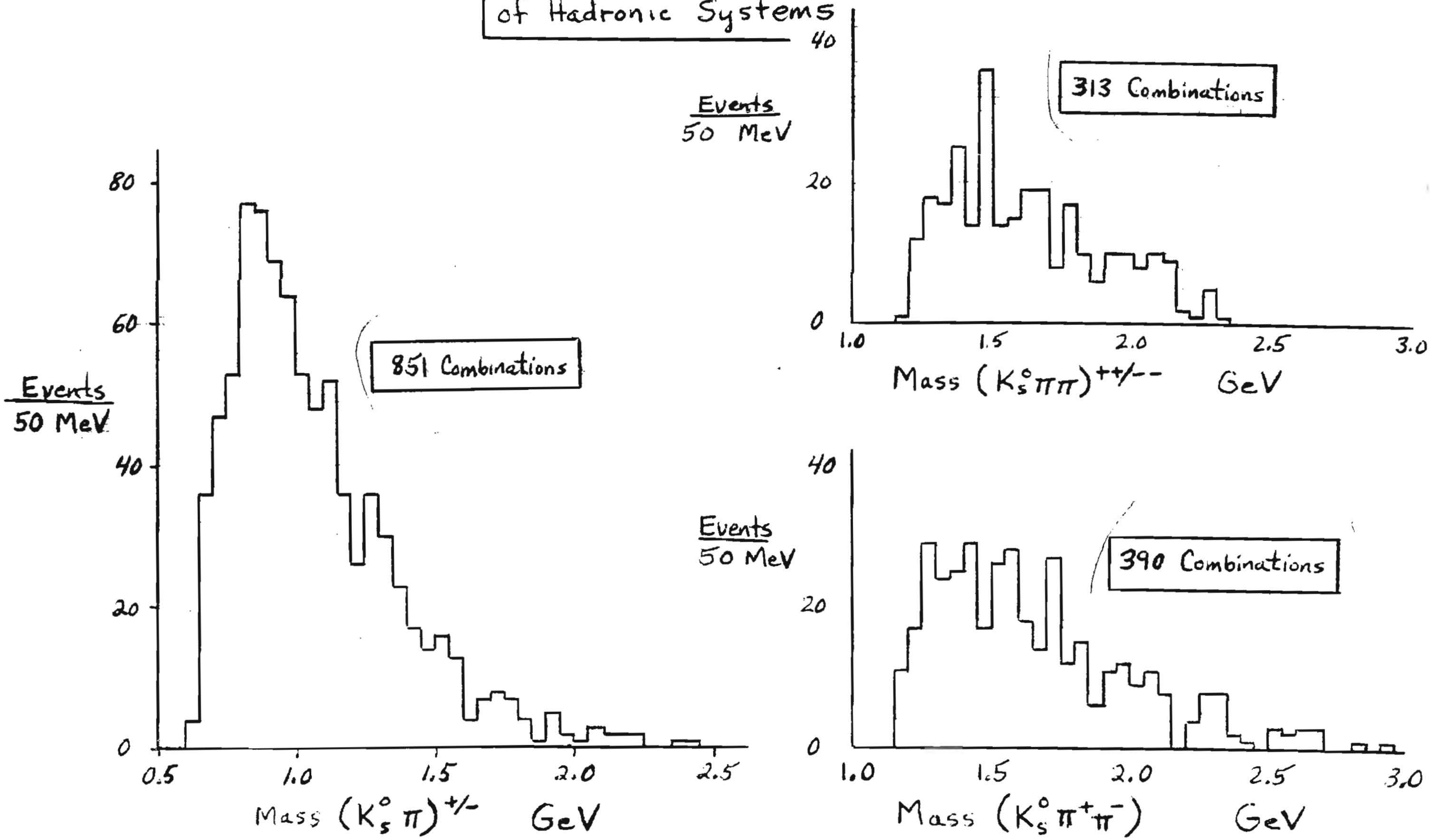


FIGURE A3
Effective Masses of Hadronic Systems

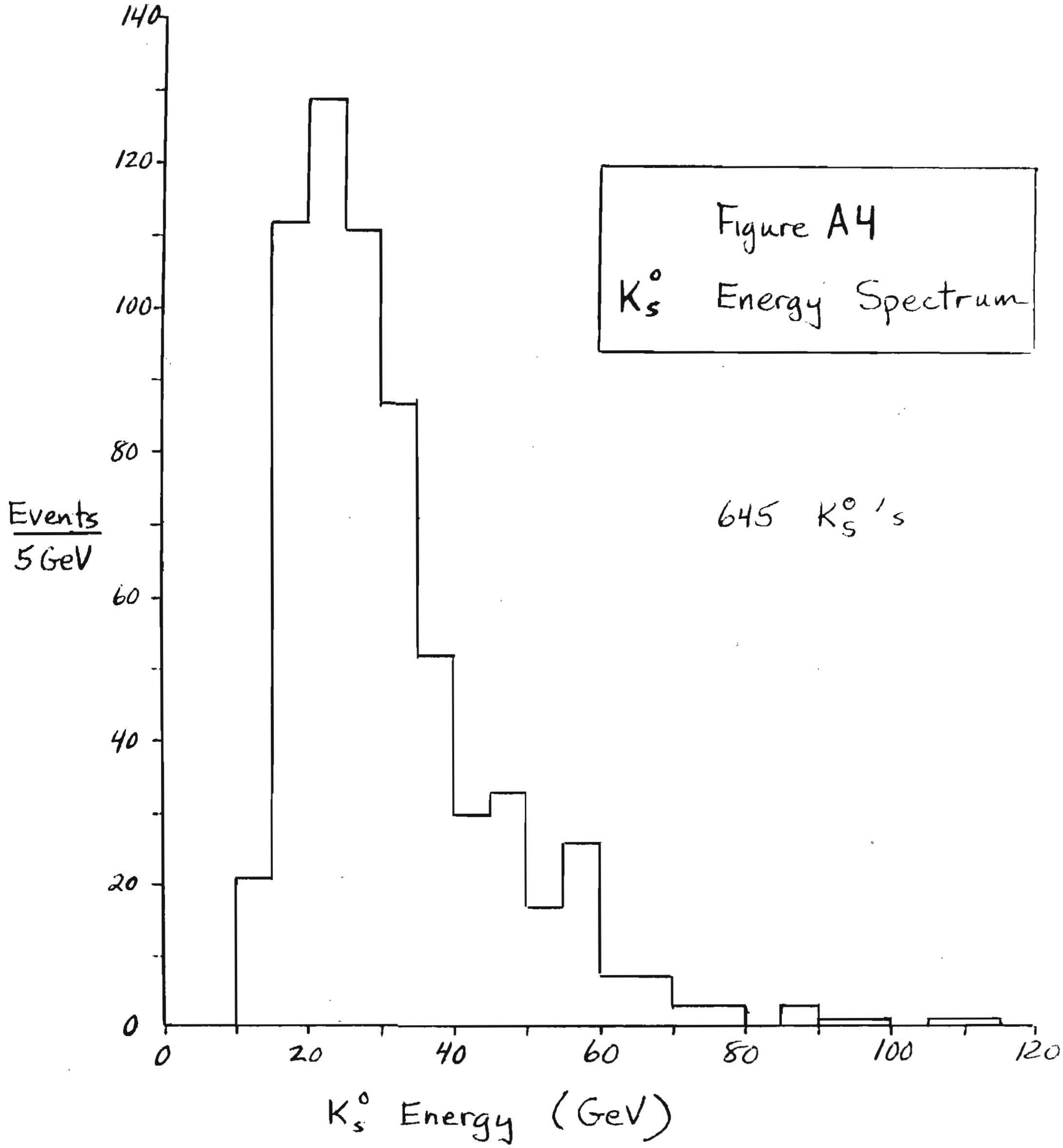


Figure A4
K_s^0 Energy Spectrum
645 K_s^0's
Events / 5 GeV
K_s^0 Energy (GeV)
0
20
40
60
80
100
120
140

APPENDIX B

LIMITS ON CHARM PRODUCTION

We take as a basic assumption that a fraction δ of the prompt leptons from strong interactions are due to associated production of charmed particles. Furthermore, since the fraction of prompt leptons seems constant or possibly even rising as $p_\perp \to 0$, and seems not to depend on energy (at high energy at least), we write:

$$\sigma(c\bar{c}X)B_\mu = \frac{\langle n_{chgd}\rangle}{2}\,\sigma(\text{inel})\,\delta R.$$

where: $\sigma(c\bar{c}X)$ = inclusive total cross section for charm production

$\sigma(\text{inel})$ = total inelastic cross section

B_μ = inclusive charm branching ratio to muons (lowest lying states).

$\langle n_{chgd}\rangle$ = average number of charged particles per inelastic collision

δ = fraction of prompt muons due to charmed particle decays

R = ratio of prompt muons to inclusive charged particles.

Experimentally, we find:

$\sigma_{\pi p}(\text{inel})$ = 19 mb [17] ($p_\pi \gtrsim 10$ GeV)

$\langle n_{chgd}\rangle$ = 8 [19] (at p_π = 200 GeV)

$\langle n_{chgd}\rangle$ = 4 (at p_π = 15 GeV)

$\delta \leqq 0.5 \pm .2$ [4]

$R = 1.0 \pm .15\times10^{-4}$ [4].

and;

i) $$\sigma(D\bar{D}X)B_\mu \begin{cases} 1.9 \pm .8\mu b\ ; & p_\pi = 15 \text{ GeV} \\ 3.8 \pm 1.6\mu b\ ; & p_\pi = 200 \text{ GeV} \end{cases}$$

Since we expect to trigger on a prompt lepton, the product σB is as relevant to our experiment as σ itself is. We also note that even if the value of δR is <u>constant</u> with energy, the cross section for charm production ~~declines~~ increases by a factor of 2 between BNL, PS energies and Fermilab energies. If it turns out that δR <u>falls</u> with decreasing energy (as some results claim), [4] then the cross section could be drastically smaller at BNL and PS energies.

We next observe that the prompt dimuons from neutrino interactions together with simple theoretical estimates of $\sigma(cX)/\sigma(\text{incl})$ predict the value of B_μ;

$$\frac{\sigma_\nu(cX)B_\mu\varepsilon}{\sigma_\nu(\text{inel})} \cong f_{2\mu c}.$$

where; $\sigma_\nu(cX)$ = inclusive deep inelastic neutrino production of charmed particles

$\sigma_\nu(\text{inel})$ = total inelastic neutrino cross section

$f_{2\mu c}$ = ratio of dimuon events to all events

ε = fraction of dimuon events from charm

Theory gives (by simple estimates);

$$\frac{\sigma_\nu(cX)^{8/}}{\sigma(\text{incl})} \sim \begin{cases} 3\% \;; & \text{for } \nu \\ 10\% \;; & \text{for } \bar{\nu}. \end{cases}$$

Experimentally:.

$$f_{2\mu}^{11/} = \begin{cases} 0.8 \pm 0.2\% \;; & \text{for } \nu \\ 2 \pm 1\% \;; & \text{for } \bar{\nu} \end{cases}$$

we assume with the experimenters[3/] that sources of prompt muons other than charm production are small, thus:

$$\varepsilon = 1.0 \quad .$$

and;

ii) $$B_\mu \sim 20 \pm 10\%$$

This value need not be very well known for our purposes. As long as it is not 50% (all charm decays are leptonic) or 0%, we are relatively unaffected. We note in passing that B_μ could not be much larger or the Fermilab $\gamma Be \to \mu^+ e^- + X$ coincidence rate would have been measurable.* Likewise, very much smaller values of B_μ give cross sections too large for known production limits.[13,14/]. We accept the 20% value as being about the right magnitude.

Combining i) and ii), we predict:

iii) $$\sigma(c\bar{c}X) \lesssim 20 \pm 10\ \mu b.$$

We take an estimate of 20 μb as a standard value for discussing limits on charm already observed. We also assume that $c\bar{c}$ states will prefer associated production of charmed particles over charmonium states like Ψ and χ (Zweig's Rule). Likewise, the lowest lying charmed states should all have comparable branching ratios to muons, and at the present uncertain level of B_μ, we don't worry about the exact charm particle to which it applies.

We now summarize the limits on branching ratios to specific final states not containing leptons. The most relevant limits come from the SPEAR charm search. We take over their limits with one change. They base their branching ratio limits on the assumption that all the cross section increase in R, the ratio of hadron production to μ pairs for the region above 4.1 GeV which is not explained by the "old physics" is caused by charmed particles. This is taken as 10.7 nb for all charm production and as 7.1 nb for the $D\bar{D}$ fraction[9/]. We believe that a more appropriate normalization would be to use the increase predicted by the colored four quark model, since the remainder of the increase is now being assigned to heavy lepton production[7/]. This raises the cross section limits of Boyarski et al. by a

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* G. Gladding, private communication

factor 1.9 in our view.[10] Other than this factor we take the limits as reported by them and include them in Table BI.

A search for associated charm production at high energy in strong interactions was reported by Bleser, et al.[12] This group attempted to see diffractively produced neutral charmed mesons or baryons decaying into two body charged states. They could not identify charged kaons from pions and vetoed before and after their analysis magnet any charged particles near the beam axis. In addition, they seem to have assumed a flat Feynman X dependence of the charm production and stated no correlation in Feynman X or rapidity of one charmed particle with its partner. Under these confused conditions, we report their limit, but feel it could be lower than the stated sensitivity by a large factor (x10 or more).

Another search for charmed particle production was carried out in a bubble chamber exposure with 15 GeV/c π^+ on p.[13] The branching ratio limits from this experiment, assuming a total charm cross section of 10μb from i) and iii) are much poorer than those from SPEAR, but are given in Table BI.

Finally, there are unpublished limits from the Fermilab 15' bubble chamber[14] about which we do not have enough information to report, and limits from our own test run of last spring which are weak, but shown to indicate how much improvement can be expected. We conclude that the SPEAR limits are by far the most rigorous if they are correctly interpreted. Nevertheless, there is room for improvement. Most important, the limits so far set in strong interactions are not convincing, and can be improved by factors of twenty or more in the presently proposed search.

Table BI

Charmed Particle Branching Ratios

from Experiment

Particle (quarks)	Final State	Branching Ratio	Source Reference
$D^\circ(c\bar{u})$	$K^-\pi^+$	< 2.4%	9
	$K^+\pi^-$	< 16 %	12
	$K_S^\circ\pi^+\pi^-$	< 5.3%	9
		< 100 %	13
		< 300 %	*
	$\pi^+\pi^-$	< 1.7%	9
	K^+K^-	< 1.6%	9
	$K_S^\circ\pi^+\pi^-\pi^+\pi^-$	< 90 %	13
	$\mu + X$	20 ± 10%	3,11
	$(e + X)$	20 ± 10%	8
$D^-(\bar{c}d)$	$K_S^\circ\pi^-$	< 600 %	*
		< 3.6%	9
		< 28 %	13
	$K_S^\circ K^-$	< 4.4%	9
	$\pi^+\pi^-\pi^-$	< 5.0%	9
	$K^+\pi^-\pi^-$	< 6.5%	9
	$K_S^\circ\pi^+\pi^-\pi^-$	< 60 %	13
	$\mu + X$	20 ± 10%	3,11
	$(e + X)$	20 ± 10%	8

Confidence limits are 90% and 95% for refs. 9,13 respectively. The limits for ref. 12 are 4 standard deviations from background. The electron branching ratio is assumed equal to the muon branching ratio.

* These values obtained from the P-369 test run, April 1975.

APPENDIX C

DETAILS OF RECOIL PROTON RESTRICTED MASS TRIGGER

1. Proton Arm Description

The attached figure, C-1, shows the approximate layout appropriate to cover the missing mass range $M_{x^-}^2 = 12.5\text{-}45\ \text{GeV}^2$ or $M_{x^-} = 3.5\text{-}6.7$ GeV for $p_{inc} = 150$ GeV.

The trigger requirement is:

(a) One of the P1 counters fires with a delay of 11 to 33 nanoseconds after the passage of a beam particle. The delay corresponds to a recoil velocity $\beta_R = 0.6$ to 0.2 or $-t = \Delta^2 = 0.04 - 0.44$ GeV for a recoil proton. In order to reduce the accidental rate we will impose a minimum pulse height requirement (a proton with $\beta = 0.2$ to 0.6 produces a pulse height corresponding to at least 2.5 x Minimum).

Because of the requirements of on-line measurement of delay time and pulse height the P1 counters are viewed by PM tubes at both ends.

(b) The MWPC's, MWPC1 and MWPC2 each record the passage of charged particles within an appropriate time gate.

(c) If necessary, we will place a counter telescope $\sim$ 10 meters downstream of the center of the magnet and require the non-appearance of the beam track in this telescope as part of the trigger. [This telescope can be designed to also suppress elastic events].

(d) Because the length of the target (40 cm) is not negligible compared to the width of the P1 counter ($\sim$ 60 cm) required by the range of polar angles for the desired missing-mass range, we intend to "divide" the target into three sections: an upstream section, a middle section, and a downstream section. Events in the upstream section of the target are required to be in coincidence with one of the four upstream counters of P1 (A to D), events from the middle section of the target are required to be in coincidence with one of the middle four counters of P1 (B to E) and events from the downstream section of the target are required to be in coincidence with one of the four downstream counters of P1 (C to E). Which section of the target the interaction occurred in is determined by summing separately the currents on the upstream middle and downstream thirds of MWPC1.

2. Off-line Analysis: Reconstruction of Recoil Track.

The horizontal and vertical coordinates of the recoil proton are each observed at three points, by the MWPC's near the target and by a pair of spark chambers (each with x and y readouts) located between the target and P1 (close to P1). In addition, the coordinates of the vertex perpendicular to the beam is known from the readout of the beam MPW chambers. Thus the direction of the proton recoil is measured with a considerable degree of redundancy.

Time of Flight.

The time of flight is measured by photomultipliers at each end of the P1 counters. A mean time circuit is used to obtain the approximate delay time (independent of vertical coordinates of proton recoil) at trigger time. We will also log the time delay of each tube. Once the proton track and vertex position have been determined, we can obtain two independent measurements of the time of flight. From previous experiments we expect a time of flight resolution (σ) of $\sim$ 0.3 nsec, which corresponds to an error on the proton recoil momentum varying from $\sim$ 2 MeV (at p = 200 MeV/c) to $\sim$ 30 MeV (at 700 MeV/c).

Off-line Discrimination Against Pions

Previous experience with a similar proton arm at Serpukhov indicates that the number of triggers due to particles other than protons is quite small compared to the number of proton recoils.

We can check this off-line (and remove π-recoil triggers) by checking the pulse height in P1. Below $\beta \sim 0.4$ the pulse height due to π-recoils is sufficiently smaller than for protons that it should be quite feasible to distinguish π's from protons. Between $\beta = 0.4$ and $\beta = 0.6$ protons (but not π's) have sufficient range to traverse P1, the 1/2" Al absorber and fire one of the P2 counters.

3. Proton-Arm Acceptance

We have calculated the acceptance of the proton arm shown in Figure C1, as a function of the missing mass M_x. To obtain the acceptance (integrated over momentum transfer) we have to know the t-dependence of the cross-section.

For the purpose of the calculation we have used

$$\frac{d^2\sigma}{dtdM} \quad \alpha \quad e^{-b(M^2)|t|}$$

$$b \;=\; 4.6 + 7.0 \times \exp\left(-34.7 \frac{M_x^2}{s}\right)$$

or $$b_2 = 21.5 - 8\, M_x^2 \;.$$

We use b_2 for small M_x^2 (defined by $b_2 > b_1$). These values of b are in agreement with both the $\pi^- p \rightarrow pX^-$ 40 GeV Serpukhov data and the results of the ANL-FNAL collaboration experiment on $p + p \rightarrow p + X^+$ at 205 GeV.[†]

The acceptance integrated over Δ^2:

$$\bar{\varepsilon}(M^2) \;=\; \int d\Delta^2 b\; e^{-b\Delta^2} \quad \varepsilon(M^2,\Delta^2)$$

is shown in the figure C2.

4. Proton Trigger Rates

To estimate the rates we need to know the diff. cross section $\frac{d\sigma}{dM_x^2}$ for $\pi^- p \rightarrow p + X^-$.

We have assumed the dependence of $\frac{d\sigma}{dM_x^2}$ on M^2 and s to be given by

$$\frac{d\sigma}{dM_x^2} \;=\; \frac{A}{M_x^2} + \frac{B}{s} \quad ^{\dagger\dagger}$$

A fit to the 40 GeV Serpukhov data gives:

$$\frac{d\sigma}{dM_x^2} = \frac{0.52 \text{ mb}}{M_x^2} + \frac{7.3 \text{ mb}}{s}$$

More recently we have looked at the result of the 145 GeV $\pi^- p$ run by the hybrid bubble chamber collaboration. Our formula agrees with the bubble chamber data to 10 or 20%.

The effective trigger cross-section, given by the product of $\frac{d\sigma}{dM_x^2}$ by the proton-arm acceptance is shown in Figure C3.

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† S. J. Barish et al., PRL 31, 1080 (1973).

†† Below $M^2 \sim 3\ \text{GeV}^2$ we use the Serpukhov value for $\frac{d\sigma}{dM^2}$, reduced by a factor $(40\ \text{GeV}/p_{inc})^{0.3}$

The integral under the curve gives:

	Elastic contribution:	0.012 mb
Inelastic:	$M_x^2 < 12.5\ GeV^2$	0.025 mb
	$12.5 < M_x^2 < 45\ GeV^2$	0.113 mb
	$45\ GeV^2 < M_x^2$	0.002 mb

Total trigger cross section

0.142 mb (elastic removed)

0.154 mb (elastic included).

We can therefore estimate the following trigger rates for:

40 cm H_2 target

10^6 π^- per 1 sec-burst

2 proton arms (one on each side)

$$0.07\ \frac{gm}{cm^3} \times 40\ cm \times 0.6 \times 10^{24}\ \frac{protons}{grams} \times \frac{(0.113 \times 2 \times 10^{-27}\ cm^2)}{pion \times proton} \times \frac{10^6\ pions}{Burst}$$

$= 386$ Trigs/Burst with $M_x^2 = 12.5 - 45\ GeV^2$

$= 483$ Trigs/Burst with all M_x^2 (not including elastic)

Including a guesstimate of the possible contribution to the trigger rate from accidental coincidences we will use:

Good trigger rate $\sim$ 400 triggers/burst

Total trigger rate $\sim \frac{483}{0.8} \sim 600$ triggers/burst.

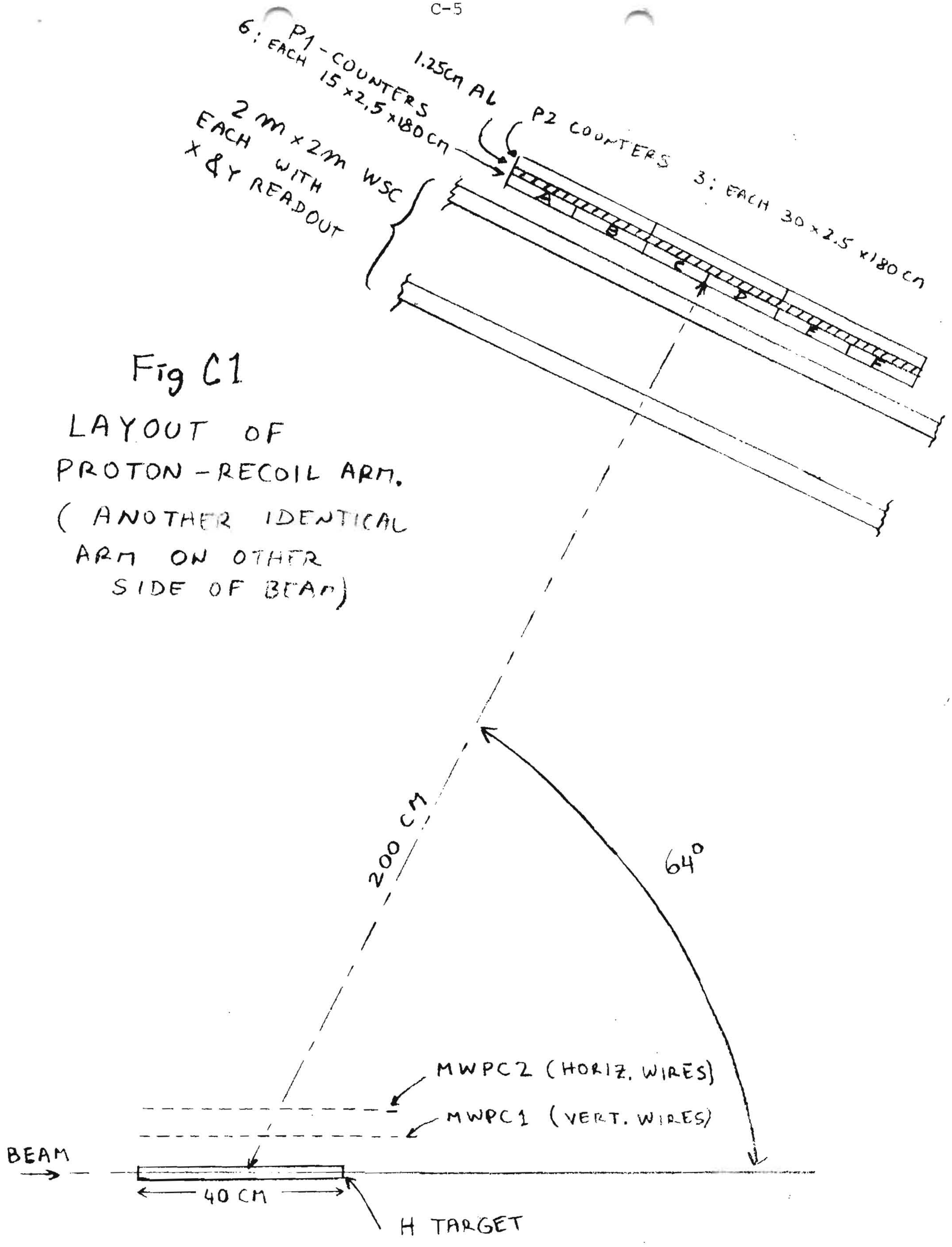
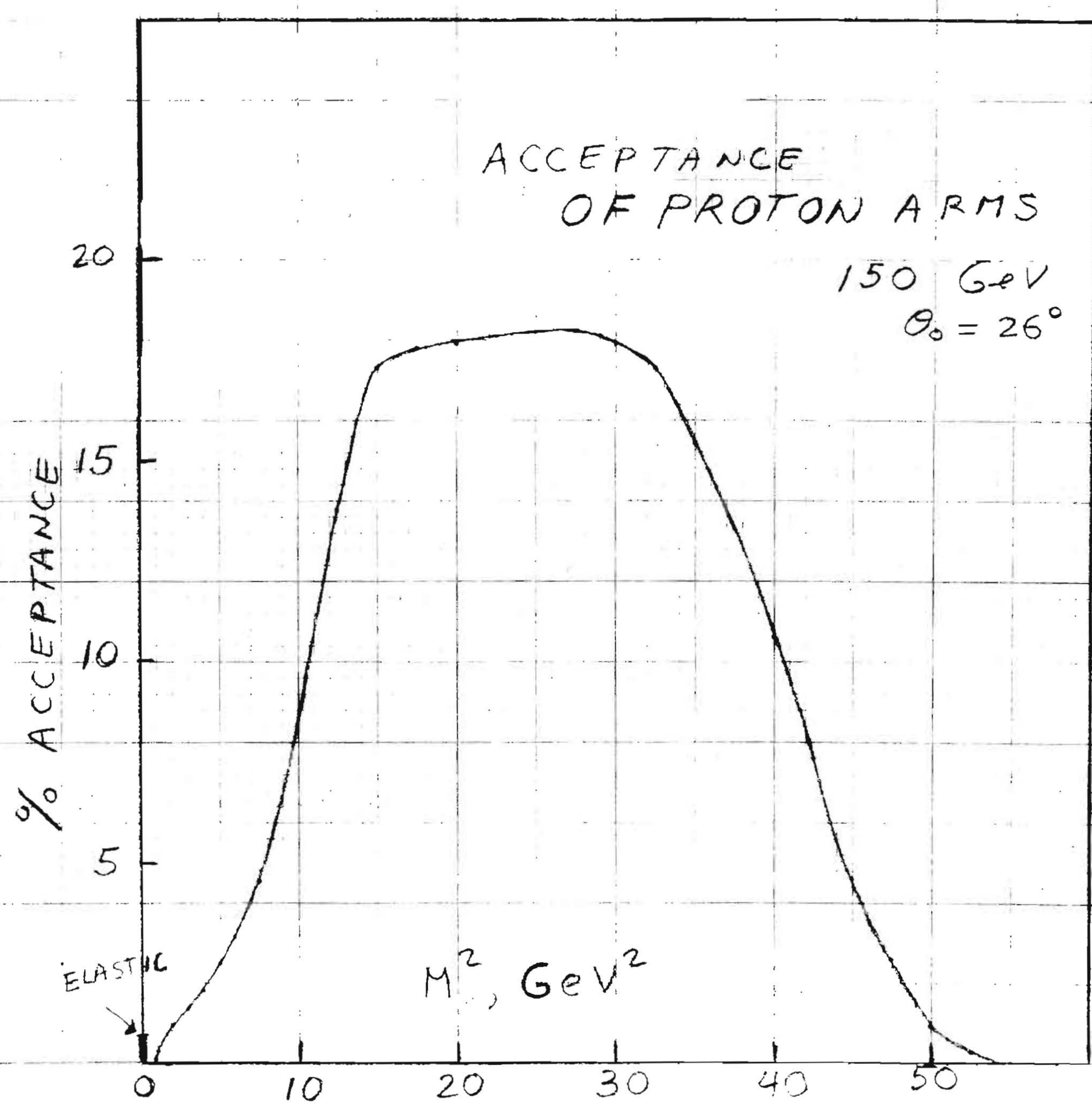


Fig C1

LAYOUT OF PROTON-RECOIL ARM.
(ANOTHER IDENTICAL ARM ON OTHER SIDE OF BEAM)

FIGURE C2



ACCEPTANCE
OF PROTON ARMS
150 GeV
$\theta_0 = 26°$
% ACCEPTANCE
20
15
10
5
ELASTIC
M^2, GeV^2
0
10
20
30
40
50

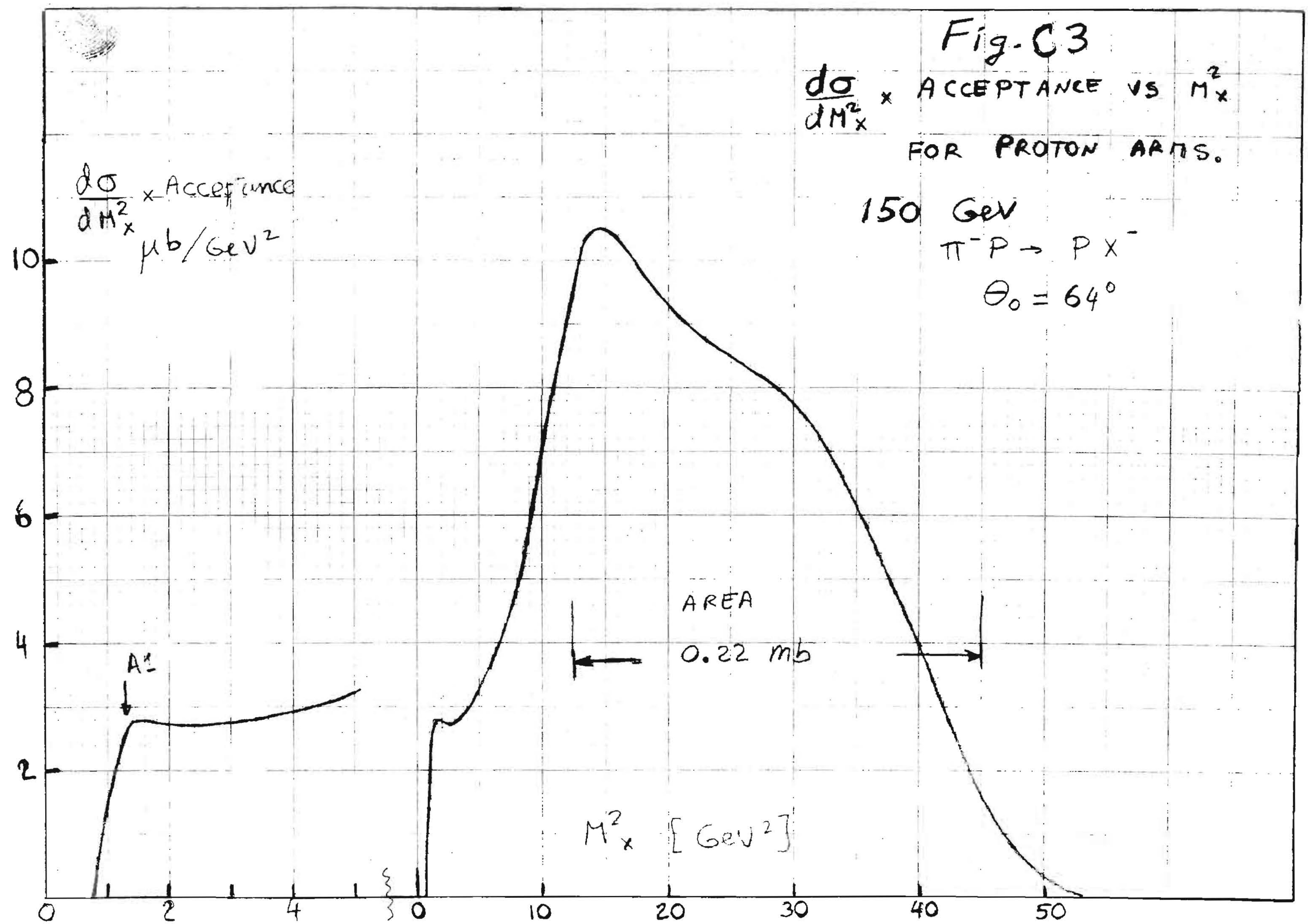


Fig. C3
$\frac{d\sigma}{dM_x^2}$ × ACCEPTANCE VS M_x^2
FOR PROTON ARMS.
150 GeV
$\pi^- P \to P X^-$
$\theta_0 = 64°$
$\frac{d\sigma}{dM_x^2}$ × Acceptance
$\mu b/GeV^2$
A1
AREA
0.22 mb
M_x^2 [GeV^2]
10
8
6
4
2
0
2
4
0
10
20
30
40
50

APPENDIX D

DETAILS OF MUON TRIGGER

1. Introduction

We have examined the effectiveness of a μ trigger for the study of events of the form $\pi^- p \to pD\bar{D}$, $D \to \mu X$ (this branching ratio is assumed to be $\sim$ 10%, see Appendix B) in the presence of a background from reactions $\pi^- p \to p(n\pi)$ with one of the π's decaying into a μ. In particular we have explored the effect of various cuts on the μ momentum and μ transverse momentum, the hope being that the background $\pi \to \mu$ is suppressed relative to $D \to \mu$ at high P_μ and/or high $P_{\perp\mu}$. We find the requirements of $P_\mu \gtrsim 20$ GeV/c and $P_{\perp\mu} \gtrsim 0.3$ GeV/c give a reasonable μ detection efficiency, although these values have not been optimised.

2. Geometry of the μ Trigger

In computing the efficiency of the μ trigger we have assumed the apparatus geometry shown in Fig. D1. The magnet center is 7.5m from the target and gives a 1.875 GeV/c transverse (horizontal) momentum kick to the particles. The μ detector is 16.25 m* behind the center of the magnet and is shielded by 2.51m of steel plus 0.46m of lead. We estimate < 1% of the hadrons will penetrate this shield. A 4 GeV/c μ will penetrate the shield.

The μ detector has the dimensions 2.4m (Y) by 7.0m (X) and is composed of vertical strip scintillation counters which determine the X position of the μ. The scintillator strips are $\sim$ 5 cm wide at the center (beam) region and are wider ($\sim$ 30 cm) at the edge of the hodoscope to give roughly equal counting rates.

With the above geometry we can eliminate low momentum μ's by requiring $|X| \leq X_{max}$, since

$$X \simeq \left(\frac{1.875 \text{ GeV/c}}{P_\mu}\right) \quad (16.25\text{m}).$$

We can also eliminate μ's with low transverse momentum by requiring $|Y/X| \leq R_{min}$, since

---

* Operating conditions will probably have the detector at 17.3m. The calculations in this appendix are not substantially changed for such a geometry.

$$Y \simeq \frac{P_\perp \sin\phi}{P_\mu} \quad (23.75\text{m}) \quad ,$$

where $P_\perp$ is the transverse momentum of the μ relative to the beam and ϕ is the azimuthal angle (to first order we assume no vertical focusing by the magnet), thus

$$\frac{Y}{X} \simeq (1.46) \frac{P_\perp \sin\phi}{1.875 \text{ GeV/c}} \quad . \quad (\text{Independent of } P_\mu)$$

For example with $X_{max} = 1.5$m, $R_{min} = 0.24$, we will require $P_\mu \geq \sim 20$ GeV/c and $P_\perp \sin\phi \geq \sim 0.3$ GeV/c.

The $|Y/X|$ cut can be imposed by arranging the scintillator strips in the "bow-tie" shape shown in Fig. D2. The circles shown in Fig. D2 correspond to the approximate (X,Y) positions of μ's with $P_\mu = 25$ GeV/c and $P_\perp \simeq 0.23$ and 0.62 GeV/c. Thus low $P_\perp$ μ's are rejected and high $P_\perp$ μ's accepted with varying efficiency.

3. μ Detection Efficiency for $\pi^- p \to pD\bar{D}$, $\bar{D} \to \mu$

To estimate the μ detection efficiency for the production of D pairs with a proton we have made Monte Carlo studies of the reactions (150 GeV/c incident π)

$$\pi^- p \to p(D\bar{D}) \qquad D \to \mu\nu \qquad (1)$$

$$\pi^- p \to p(D\bar{D}) \qquad D \to K\mu\nu \qquad (2)$$

$$\pi p \to p(D\bar{D}\pi) \qquad D \to \mu\nu \qquad (3)$$

$$\pi p \to p(D\bar{D}\pi) \qquad D \to K\mu\nu \qquad (4)$$

We have assumed a t distribution of the form e^{4t} for the protons and we assumed the $(D\bar{D})$ to have a mass of 4.2 GeV, and to decay isotropically into D and $\bar{D}$ (a D mass of 2.0 GeV was assumed). For reactions (3) and (4) we assumed the $(D\bar{D}\pi)$ to have a mass of 4.6 GeV, and to decay isotropically into $(D\bar{D})$ and π where again the $(D\bar{D})$ has a mass of 4.2 GeV. Finally, we assumed the two or three body decays of the D's to follow phase space. In Fig. D3 we present the percentage of μ's detected for various X and $\frac{Y}{X}$ cuts for the charmed particle production models (1) and (2). We see that the 2 body decay modes $D \to \mu\nu$ produce higher triggering efficiencies than the 3 body decays. The efficiencies are in the range 25–50% for operation with $|X| < 1.5$m and $|\frac{Y}{X}| \geq 0.24$. We have found very little difference

APPENDIX D

DETAILS OF MUON TRIGGER

1. Introduction

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* Operating conditions will probably have the detector at 17.3m. The calculations in this appendix are not substantially changed for such a geometry.

between the $(D\bar{D})$ and $(D\bar{D} + \pi)$ systems, and the $(D\bar{D}\pi)$ results are not shown.

4. μ Detection Efficiency for the Multi-π Background

To estimate the μ detection efficiency for the background reactions $\pi^- p \rightarrow p(n\pi)$, $\pi \rightarrow \mu\nu$, we have used the 30" Hybrid Bubble Chamber Consortium data for 147 GeV/c $\pi^- p$ interactions. This bubble chamber sample consists of 15,960 events (corresponding to a total ^-p cross section of 24.4 mb, and an inelastic cross section of 21.1 mb) with an average charged particle multiplicity $\langle n \rangle = 7.40$. 784 of these events have an identified proton (≤ 1.4 GeV/c) and a missing mass squared (MM^2) recoiling against the proton in the range $12.5 \leq MM^2 \leq 45$ GeV^2. For these 784 events $\langle n \rangle = 5.35$, thus our proton recoil trigger (see Appendix C) limits the multiplicity. This point is illustrated in Fig. D4.

For the above 784 proton recoil events we have assumed all particles other than the proton are π's and let these π's decay $\rightarrow \mu\nu$ through the geometry described in Section 2 of this appendix. Since the $\pi \rightarrow \mu$ decay probability is low ($\sim$ 4% for our flight path of 23.25m) we have enhanced the decay probability by a factor of 25 to increase our "μ statistics". In Fig. D3 we present the percentage of the 784 events with a detected μ (where the factor of 25 has been removed) for various X and Y/X cuts.

From Fig. D3 we see the $\pi \rightarrow \mu$ background is suppressed relative to the $D \rightarrow \mu$ models as the X and Y/X cuts are made more restrictive. The cuts $|X| < 1.5$m, $|Y/X| \geq 0.24$ give reasonable detection efficiencies (circled points in Fig. D3), although no attempt has been made to optimise these values.

Finally, we show in Fig. D4 the effect of the μ with $|X| < 1.5$m, $|Y/X| \geq 0.24$ requirements on the charged multiplicity. We find $\langle n \rangle = 6.3$ with the events concentrated in the 4, 6, and 8 prongs.

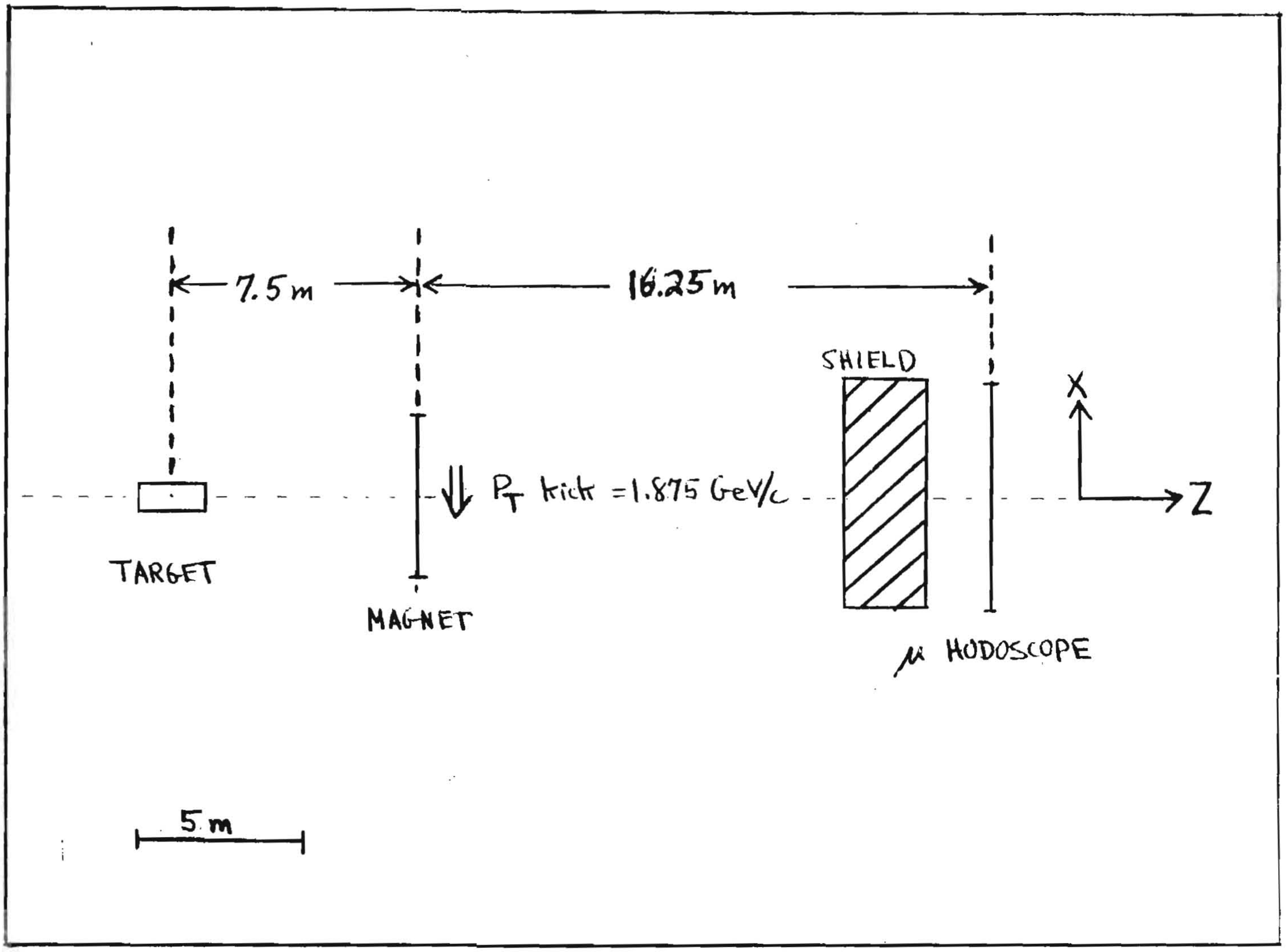


Figure D1 μ Trigger Geometry

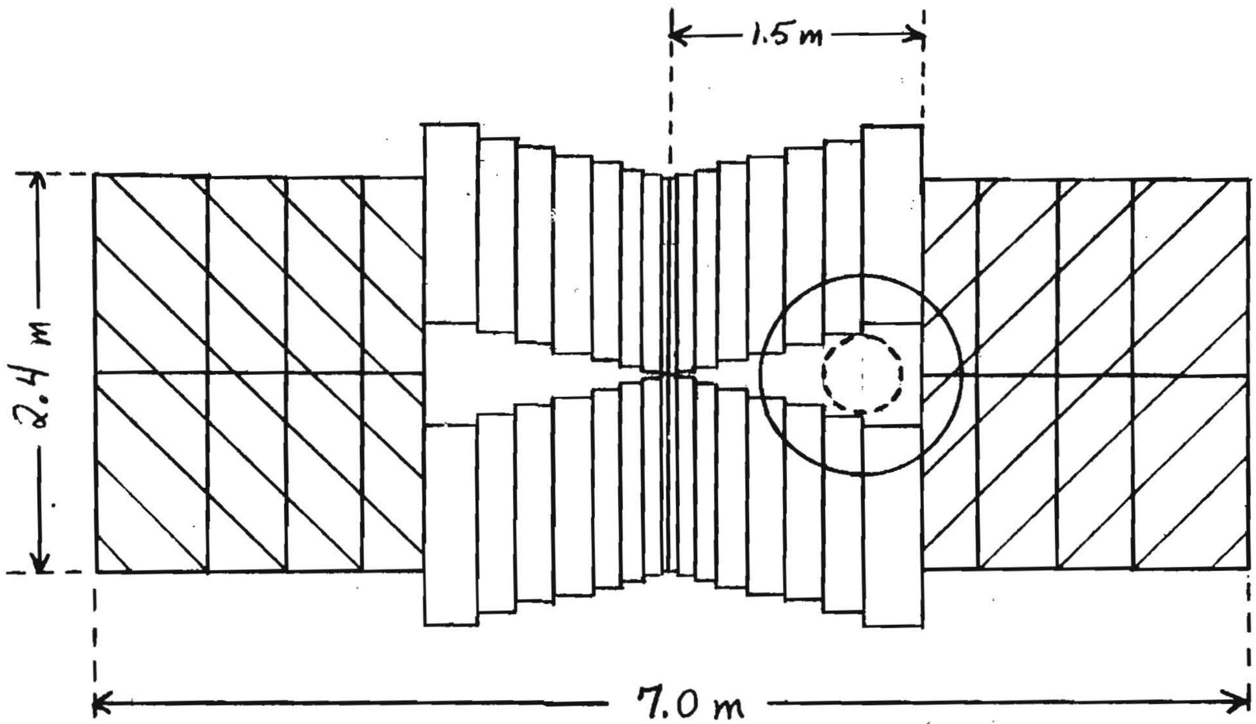
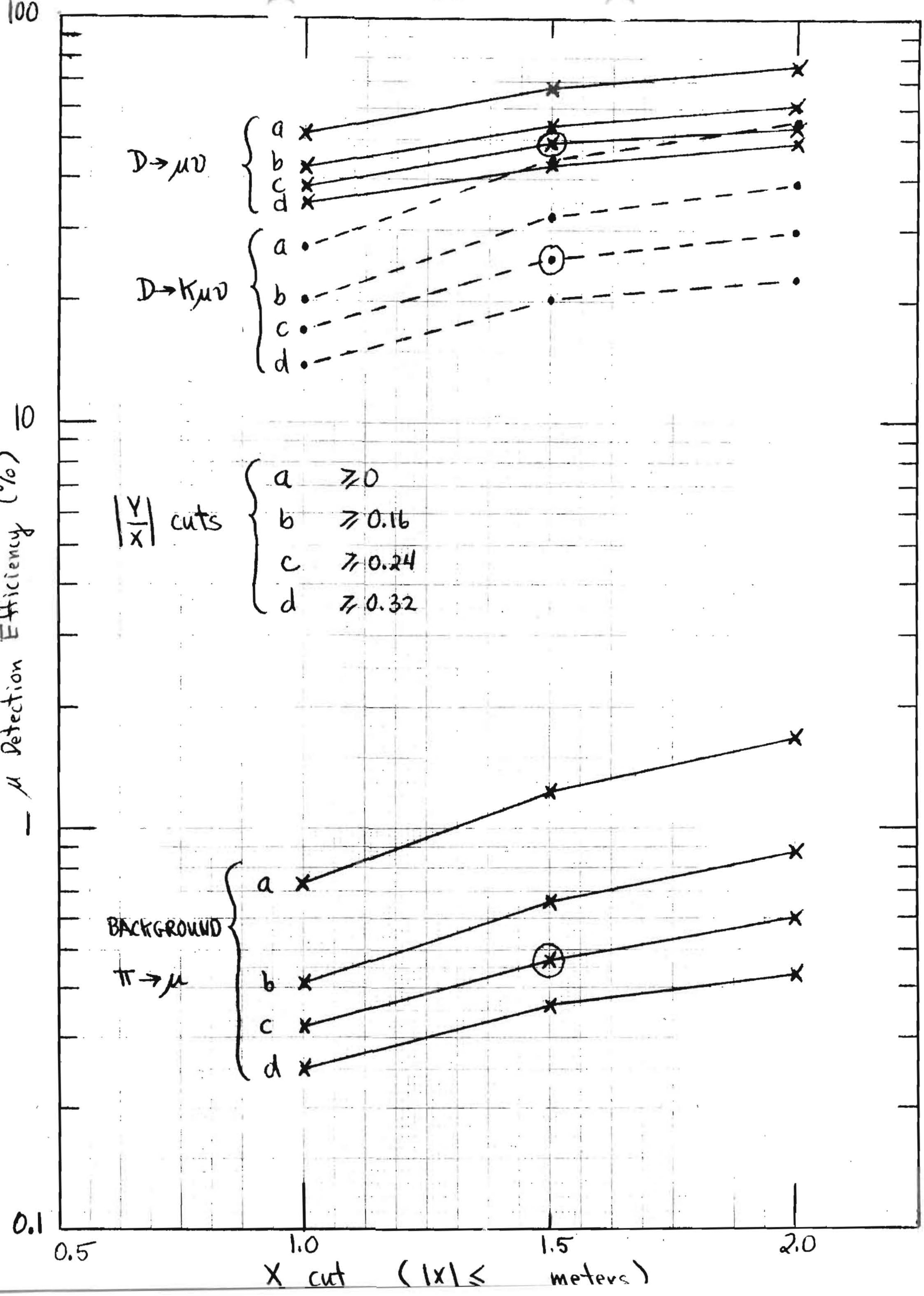


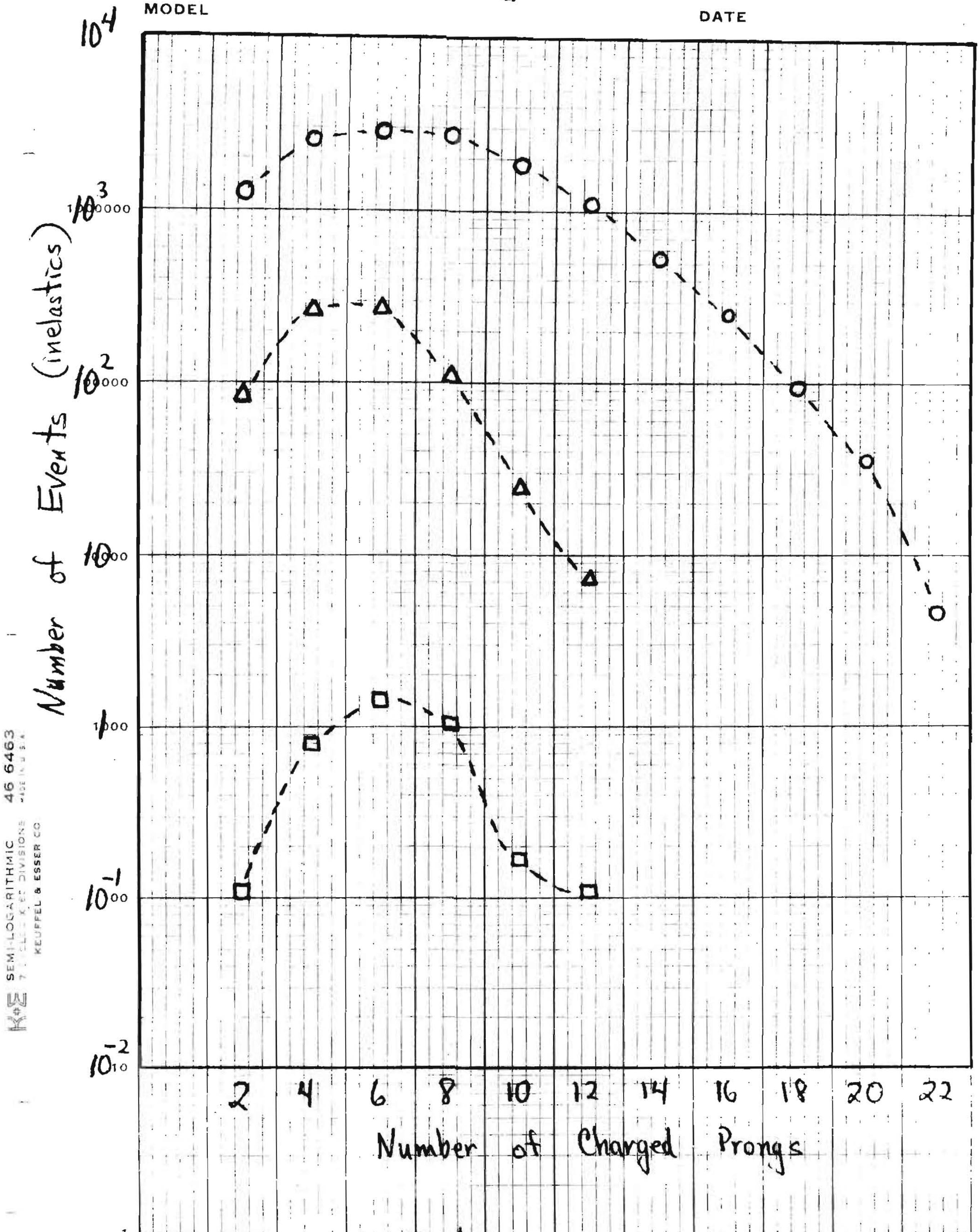
Figure D2. The μ Hodoscope "Bow-Tie"

The scintillator strips are arranged for the cuts $|X| < 1.5$ m, $|Y/X| \geq 0.24$. The shaded counters will be latched. The solid circle corresponds to μ's with $P_\mu \sim 25$ GeV/c, $P_{\perp\mu} \sim 0.62$ GeV/c. The dotted circle corresponds to μ's with $P_\mu \sim 25$ GeV/c, $P_{\perp\mu} \sim 0.23$ GeV/c.



100
10
1
0.1
μ Detection Efficiency (%)
D→μν
a
b
c
d
D→Kμν
a
b
c
d
|Y/X| cuts
a ≥0
b ≥0.16
c ≥0.24
d ≥0.32
BACKGROUND
π→μ
a
b
c
d
0.5
1.0
1.5
2.0
X cut (|X| ≤ meters)

Fig D4



○ = All Events

△ = Events with proton and $12.5 \leq MM^2 \leq 45$ GeV^2

□ = Events with proton, $MM^2 = 12.5 - 45$ GeV^2, and a detected μ with $|X| < 1.5$m, $|Y/X| \geq 0.24$

APPENDIX E

DETAILS OF TWO MUON TRIGGER

The philosophy of this trigger is to provide a sample of events which is greatly enriched in ψ and ψ' content, and thus by Zweig's rule, hopefully obtain a sample very rich in charmed particles. The sample is produced by triggering on events in which there are two muons in the final state. We thereby select preferentially, events in which ψ particles are produced which decay into μ^+ and μ^-. To do this we propose to use the hodoscope installed downstream of the hadron absorber for E-331; we require two non-adjacent elements of this array to fire as an indication of a muon pair. The acceptance for ψ depends on the production mechanism and in order to obtain an estimate, a model has been assumed in which the ψ is produced with transverse momentum distribution $e^{-1.6p_\perp}$. The acceptance is calculated for various values of $X' \equiv p_{||} / (p_{||\,max}^{\;2} - p_\perp^{\;2})^{1/2}$. $p_{||}$ is the center-of-mass momentum along the direction of the incident beam pion. We assume the invariant differential cross section $E\, d^3\sigma/d\vec{p}^{\,3}$ is proportional to e^{-6X} based on Blanar et al.[21] Production from this model has been calculated for 225 GeV/c pions incident on protons. The results are shown in Table E1.

Table E1

X'	ACCEPTANCE
0.0-0.1	18%
0.1-0.2	32%
0.2-0.3	55%
0.3-0.4	63%
0.4-0.5	76%
0.5-0.6	79%
0.6-0.7	82%
0.7-0.8	86%
0.8-0.9	89%
0.9-1.0	91%

If we integrate the Blanar cross section times branching ratio and the acceptance given in Table E-1, we calculate the maximum possible event rate:

$$R = I_o \, t N_o \sigma(X' > 0) \; B_{\mu\mu} \; \overline{Accep}$$

$$R = (10^6 \text{ pulse}^{-1})(2.8 \text{ gm/cm}^2)(6\text{x}10^{23})(10^{-32} \text{ cm}^2)(.32)$$

$$R = 5.39\text{x}10^{-3} \text{ events per pulse}$$

For the proposed total illumination of $2\text{x}10^{11}$ pions, we get a total yield:

$$N_{\psi_{2\mu}} = (2\text{x}10^5)(5.4\text{x}10^{-3})$$

$$N_{\psi_{2\mu}} = 1100 \text{ events.}$$

If we believe Zweig's rule

$$\sigma(X > 0) B_{2\mu} = 10 \text{ nb}$$

$$\overline{Accep.} = .32$$

$$R = I_o t \; \sigma BA$$

$$= (10^6)(10^{-32})(.32)(40)(.07)(6\text{x}10^{23})$$

$$= .896 \text{ x } 10^{-3} \text{ per pulse}$$

$$R = (5.37\text{x}10^{-3})(276) = 1.48 \text{ hr}^{-1}$$

This yield is the maximum psi production which is accepted by the CCM spectrometer. It will give rise to a background dominated trigger rate which has not yet been calculated in detail, but which can be estimated from the single muon trigger rates of Appendix D. If we square the single muon rate for the full hodoscope, we get a raw trigger rate for two muons of $2.5\text{x}10^{-4}$ per beam particle or 250 per pulse. Clearly this trigger element will have to be combined with one of the other building block trigger components described in Appendices C, D, F to arrive at a practical system. This additional restriction will reduce the maximum possible yield of psi's by some factor f. If f is no worse than a factor 10, we can hope for a practical yield of perhaps 100 psi's. We have not yet completed the background trigger rate calculations, but the sources can be identified:

(1) Secondary pion decay in flight.

(2) Pion 'punch-thru' of the hadron shield.

(3) Inclusive prompt muon production.

(4) Muon halo and muons in the beam.

These effects will be reduced by the selective use of the following hardware measures:

(1) Thickening the hadron shield in the incident beam area.

(2) Requiring in the trigger two or more secondary particles outside the beam before the hadron shield.

(3) Omitting a region around the median plane from the two muon triggering hodoscopes or from the hodoscope before the hadron shield.

(4) Requiring one muon up and the other down in the trigger.

(5) Using the halo veto to veto muons from the berm.

These measures work in the following ways:

(1) Obviously serves to prevent one or more incident beam or high momentum secondary particles from punching through to simulate final state muons.

(2) Time correlates muons after the hadron shield with those before and improves the rejection of effects due to beam 'punch-through'.

(3,4) Impose lower limits on the vertical angle between the two muons.

These efforts will bias the trigger against pion decay in flight (these decay muons have, because of limited transverse momentum, limited vertical separation, see Appendix D). In addition, the background effects can be further reduced during analysis to leave a pure sample of ψ containing events. 'punch-through' will be recognizable because tracks before and after the hadron shield will not link cleanly. Muons from pion decay in flight will give rise to an effective muon pair mass distribution which is rapidly falling with increasing mass. This background will be even less troublesome at the ψ mass because our mass resolution allows tight cuts to be applied in ψ selection.

The measures suggested above should reduce the trigger rate to a manageable rate for the apparatus and one that generates events in which it would be a reasonably easy job to find the genuine ψ events. There is no easy method of obtaining a trigger bias against $\mu^+\mu^+$ or $\mu^-\mu^-$ events. This may not be a disadvantage because high mass pairs of this kind may be produced in the semileptonic decay of associated production of charmed particles.

We characterize this trigger approach as a search for a small signal which is very clean, in contrast to the other triggers which depend more heavily on statistics to exhibit the signal above background. We emphasize, however, that this approach differs radically from the experiment of Pilcher, et al. (E-331) in that we use the ψ as a filter, but still expect to reconstruct the associated charmed particles from their hadronic decays. This is intrinsically forbidden to E-331 by the steel plug immediately behind their target.

APPENDIX F

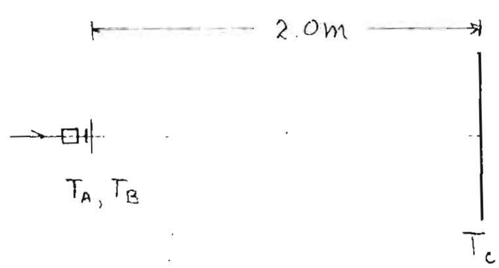
DETAILS OF K_S^0 TRIGGER

The purpose of the trigger is to enhance the fraction of events that contain one or more neutral decaying kaons. The procedure is to measure the pulse height in a scintillation counter immediately downstream from the target and to compare this value with that obtained from a scintillation counter 2.0 meters further downstream. The additional two charged particles which come from the reaction $K_S^0 \to \pi^+\pi^-$ will contribute to the pulse height of the downstream counter but not to the one near the target. Thus, events which contain neutral kaon decays should have a larger pulse height in the downstream counter relative to the upstream counter.

Several phenomena occur which can thwart the goals of the triggers. The undesirable effects of these phenomena may be either to lose valid events which contain a decaying neutral kaon, or, to incur false triggers in which no neutral decaying kaon occurs. We list several:

1) Statistical fluctuations in energy loss of the charged particles passing through the scintillators (Landau-Vavilov fluctuations.
2) Secondary interactions of charged particles and gamma-rays in the scintillators and other material.
3) Variation of light collection efficiency in the scintillators.
4) Accidentals and pile-up

We will now discuss these sources of trigger errors both theoretically and as measured in our completed test run, Charm Search P-369. The following figure shows the relevant portion of the apparatus of P-369:

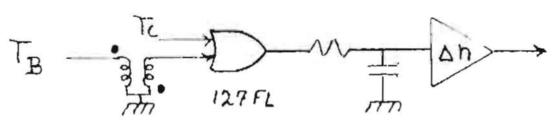


The counter dimensions were

T_A	1" x 1" x 1/16"
T_B	3-1/2" x 3" x 1/16"
T_C	20" x 14" x 1/16"

T_A and T_B were viewed by one RCA 8575 photomultiplier each while T_C was viewed by eight Phillips 58AVP tubes.

The pulse height from counter T_C is used as one input to a linear fan-in circuit. The signal from counter T_B is inverted by means of a 1: 1 inverting transformer and used as the second input to the linear fan-in. An RC integration network with a time constant of $\sim$ 20 ns is used at the output of the fan-in to smooth out short term fluctuations in pulse height. The smoothed output of the linear fan-in is then fed into a threshold discriminator called the Δn discriminator.



Statistical Fluctuations

The distribution of energy losses of minimum ionizing particles passing through a scintillation counter such as T_A was calculated using the theory of Landau-Vavilov. A plot of expected counting rate vs. discriminator threshold is shown in Fig. F1 along with the experimental values for counter T_A and T_C. There is close agreement between the theoretical curve and the no-target curve for T_A down to a few tenths of one percent level. We expect a 0.3% interaction rate in a 1/16" counter which is consistent with the data. The target-in rate is also plotted in the same figure. The beam interaction rate in the target, 1.6 cm of Lucite, is expected to be 3%. The excess counting rate near the relative discriminator threshold of 2 to 2.5 is in satisfactory agreement with that expected.

Note that the threshold curve for counter T_C is almost identical to that of T_A despite the large relative size difference. We draw two conclusions from these data:

1) At least we know how to calculate the pulse height distribution for single particles passing through a scintillator.

2) The response of the large (20" x 14") counter is very similar to the small (1" x 1") counter.

Secondary Interactions.

Particles originating from a beam-target interaction may have secondary interactions which produce spurious contributions to the pulse height in counter T_C. The amount of material which contributes to this process is :

a) Some fraction, we take 1/2, of counter T_B.

b) 2 meters of He at atmospheric pressure

c) Some fraction, again we take 1/2, of counter T_C.

d) Various thicknesses of counter wrapping material, He bag window, etc.

	Thickness		gm/cm^2		Col.Length	Rad. Length
Scintillator	1/16"	=	0.16	=	0.29%	0.37%
He	2m	=	0.036	=	0.07%	0.04%
Misc.	1/32"	=	0.08	=	0.14%	0.18%
					0.50%	0.59%

The number of collision lengths must be multiplied by the average multiplicity of charged particles, about 5 for our trigger, and the radiation length number should be multiplied by the average number of γ's, about 4. Therefore we calculate a total secondary interaction trigger probability of $5 \cdot 0.50 + 4 \cdot 0.59 = 4.4\%$. This estimate holds for a Δn discriminator threshold set at 2. For $\Delta n = 3.5$, where a comparison can be made with the P-369 charm test, the contribution due to photon conversions should be multiplied by a factor which is the probability that two extra partcles looks like 4. This calculated probability is 0.2 leading to a total secondary interaction trigger probability of $5 \cdot 0.5 + 0.2 \cdot 4 \cdot 0.59 = 3.0\%$. This value is somewhat higher than that inferred from the data ($\sim 1\%$. See Appendix A).

Uniformity of Light Collection

A penetrating β-ray source was used to explore the uniformity of pulse height response over the entire surface of the 20"x14" scintillator. A variation of ± 8% was observed. The observed variations could be attributed to measured non-uniformity in thickness of the plastic scintillator. The average number of photo-electrons per minimum ionizing track was about 60-65.

Accidentals and Pile-up

With a beam intensity of 10^6 pions per pulse, one must expect instantaneous rates in counter T_B of the order of several MH_z. Since we integrate the pulse in T_B with a 20 ns time constant then the pile-up problem begins to become annoying, e.g., at 2 MH_z and $3\tau = 60$ ns the pile-up probability is $2 \cdot 10^6 \times 60 \cdot 10^{-9} = 12\%$. Therefore electronic circuitry must be installed to prevent triggers from occurring when two beam (or beam plus halo) particles enter the area. This is no problem, however, there will be a loss of effective beam intensity by 10-15%.

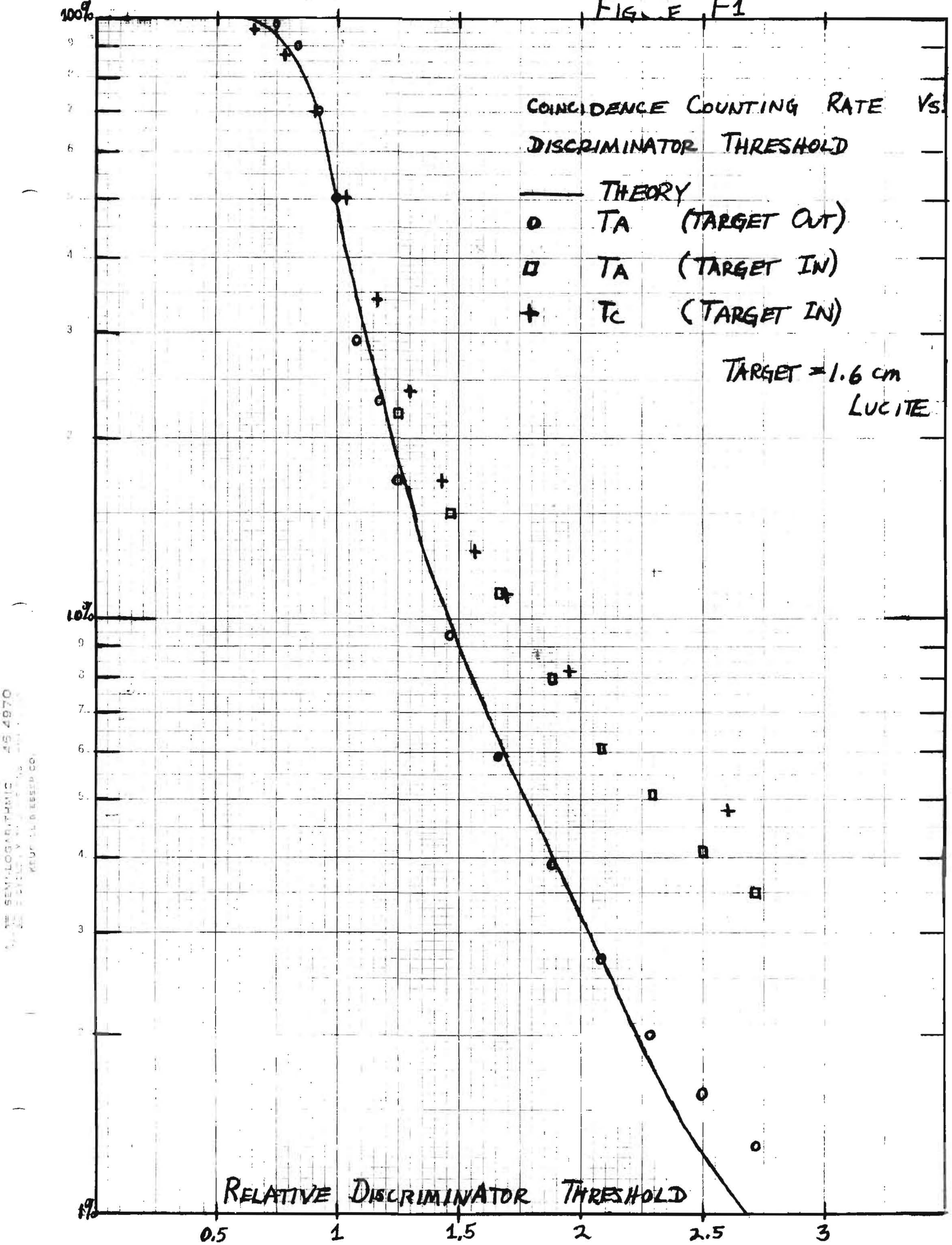


FIGURE F1
COINCIDENCE COUNTING RATE VS.
DISCRIMINATOR THRESHOLD
THEORY
o TA (TARGET OUT)
□ TA (TARGET IN)
+ TC (TARGET IN)
TARGET = 1.6 cm
LUCITE
100%
10%
1%
0.5
1
1.5
2
2.5
3
RELATIVE DISCRIMINATOR THRESHOLD

APPENDIX G

ESTIMATES OF BACKGROUND

We have used the results of the hybrid bubble chamber run to estimate the background to be expected under a possible D meson decay peak. The bubble chamber experiment has already been discussed in Appendix D in the description of μ trigger rates from the reaction $\pi^- p \rightarrow p(n\pi)$ with one of the π's decaying into $\mu\nu$. In this appendix we wish to use the same bubble chamber data to obtain estimates of the number of mass combinations we expect in a mass bin in the D region. We always assume that we have a p and μ trigger and we therefore study the number of mass combinations for the two reactions:

$$\pi^- p \rightarrow p\pi_d^{\pm}(m\pi) \tag{1}$$

and

$$\pi^- p \rightarrow p\pi_d^{\pm}(K^{\pm}m\pi) \tag{2}$$

where $\pi_d^{\pm} \rightarrow \mu^{\pm}\nu$

We study 6 and 8 prong events with low momentum protons and use Monte Carlo techniques(as in Appendix D) to obtain the proper description of $\pi\mu$ decays. The other pions (other than the one which decayed into the μ) were then used to form various charge combinations to obtain the background estimates.

We expect that we will have a mass resolution corresponding to 25 MeV full width at half maximum for multipion systems. This estimate is based on the value of 15 MeV full width at half maximum observed for the K°'s in the P-369 run described in Appendix A. In the bubble chamber run the statistics were relatively small; we therefore have used the number of mass combinations between 1.5 and 2.5 GeV (reduced by a factor of 40) to obtain our estimate of the number of mass combinations in a 25 MeV bin at 2 GeV. A typical mass spectrum from the bubble chamber events with recoil proton and π-μ decay selected by Monte Carlo is shown in Fig. G1.

We will give the number of mass combinations expected for a 25 MeV bin near 2 GeV for our basic reactions (1) and (2). In all cases we have normalized the proton events from the bubble chamber data to correspond to $8 \cdot 10^7$ proton recoils. The number of μ decays and mass combinations were then computed in a straightforward way for the π reaction (1). For the K reaction (2) we have calculated the number of $Km\pi$ combinations for three sets of conditions:

Condition a. all $K(m\pi)$ combinations

Condition b. those $K(m\pi)$ combinations for which all the particles in the $K(m\pi)$ combination have momentum larger than 10 GeV.

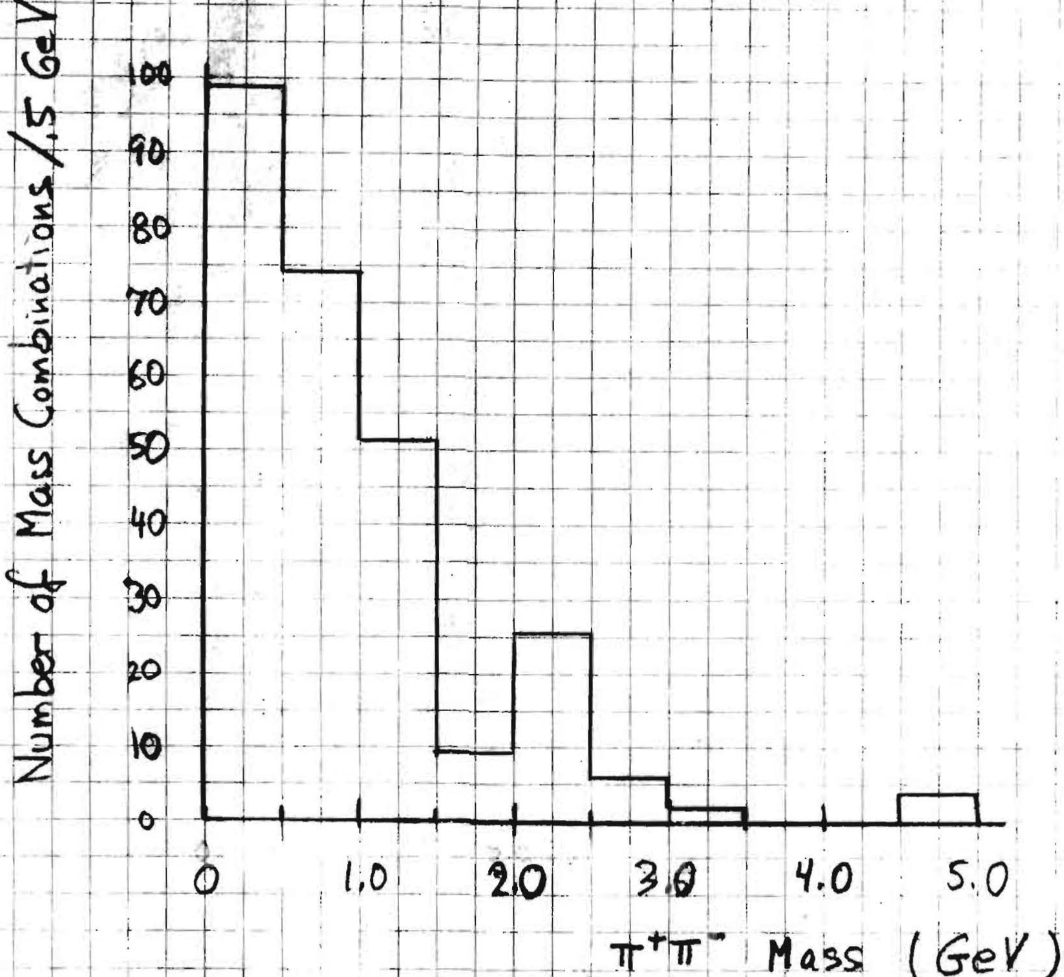
Condition c. those $K(m\pi)$ combinations for which the K particle has momentum between 10 and 25 GeV (allowing it to be identified as a K particle in the Cerenkov counter).

For all the K's from reaction (2) we required the K particle to have the same charge as the μ.

The purpose of exploring conditions b. and c. was to see the reduction in the background which can be achieved by simple off-line analyses. Condition b seeks to reduce background by noting that typical momenta in $D\bar{D}$ decay are higher than the momenta in the usual multi-π background. Condition c. reduces background by requiring an identified charged K meson and therefore reduces the background because the K/π ratio is usually $\sim 1/10$ and because the number of mass combinations is now reduced. In calculating the possible $(Km\pi)$ combinations, the computer program assigned the K mass to the various track candidates in turn and the corresponding $(Km\pi)$ combinations were then computed (if the other auxiliary conditons in b. or c. were satisfied).

The results of these background studies are given in Table G1 for 4 and 6 prong events. The decay μ was required to have $|x| < 1.5$ m and $|y/x| > .24$ as described in Appendix D. The numbers of mass combinations have been normalized to yield the number of mass combinations in a 25 MeV bin at 2 GeV for $8 \cdot 10^7$ recoil protons.

Fig G1



Number of $\pi^+\pi^-$ mass combinations with p and simulated μ trigger seen in 6 prong events. The sample is based on 283 six prong with proton events. The number of μ decays was enhanced by a factor of 420 using Monte Carlo techniques.

Table G1

Background mass combinations in 25 MeV bin at 2 GeV, $8 \cdot 10^7$ proton recoils

		4 prongs				6 prongs			
		multi π	K, mπ			multi π	K, mπ		
			a) all	b) p ≥ 10	c) K ident		a) all	b) p ≥ 10	c) K ident
μ^-	+ −	257	484	29	4	553	1441	276	32
	+ + −	0	0	0	0	1747	2359	74	75
	+ − − *	0	0	0	0	0	0	0	0
	+ + − −	0	0	0	0	1001	1812	0	74
	subtotal	257	484	29	4	3301	5607	350	181
μ^+	+ −	0	0	0	0	451	645	120	12
	+ + − *	0	0	0	0	0	0	0	0
	+ − −	0	0	0	0	1372	1390	146	15
	+ + − −	0	0	0	0	0	0	0	0
	subtotal	257	0	0	0	1823	2035	266	27
Total		257	484	29	4	5124	7642	616	208

* charge combination forbidden in $D\bar{D}$ decays

APPENDIX H

LIQUID HYDROGEN TARGET

The characteristics of the new target cup are the same as those used for other experiments observing low energy proton recoils on both sides of the beam. The liquid hydrogen appendix is to be 40 cm long and 2.5 cm diameter centered on the beam, which is to be about 1 cm diameter. The cylindrical end walls and end caps should be as thin as safety rules permit.

The vacuum jacket surrounding the liquid hydrogen appendix should also have thin windows for beam entry and exit and for the recoil protons on the right and left sides. The latter will leave the target at angles of about 64.5° relative to the beam direction and between ± 36° azimuthally relative to the horizontal plane. Thus, if the thin side windows are 6 cm from the beam axis, they must be about 9 cm high and must extend from the upstream end of the appendix to about 6 cm beyond the downstream end.

The superinsulation around the appendix should be adequate to prevent bubbling but as thin as possible where the protons leave.

APPENDIX I

GAS CERENKOV COUNTER

A twenty-cell gas Cerenkov hodoscope is included in the downstream equipment (Fig. 1), for secondary particle identification. The track length is 1.8m of gas at atmospheric pressure. In each cell a curved mirror aimed at the center of the magnet focuses Cerenkov light into a funnel on a 5" PM tube (RCA 4522).

The average number of photoelectrons per particle is

$$\bar{N} = A\ L\ \theta^2 = 1.8\text{x}10^4\ \theta^2$$

where we have taken A = 100 per cm[20/] for this set-up. The angle θ is, of course, a known function of the refractive index and velocity. With the Poisson distribution of photo-electrons,[20/] the efficiency is a known function of $\bar{N}$ and the discrimination **level** of **the** electronics. If we can operate at a discrimination level corresponding to a single photoelectron, then $\bar{N}$ = 3 will give 95% detection efficiency; with a perhaps more realistic threshold of T = 2 photoelectrons, $\bar{N}$ = 4.75 is needed for 95% efficiency.

Our main concern is identification of charged K's in a large background of π's. We propose to do this by use of a refractive index and a discrimination level providing better than 95% efficiency for π's and worse than 5% efficiency for K's.

The figure shows two families of curves of index vs. momentum. The family on the left is the lower momentum boundary, p_{min}, of the π-detection region, the curves corresponding to T = 1, 2, 3, 4 equivalent photo-electrons. To the right of the curve a pion is detected with better than 95% efficiency. The family of curves on the right is the upper momentum boundary, p_{max}, of the K non-detection region. To the left of the curve a kaon has less than 5% chance of giving a detected pulse. A particle in this momentum range that fails to give a Cerenkov pulse is identified as a kaon (with use of the recoil proton trigger, proton contamination should be negligible).

We wish to maximize the momentum range of K/π discrimination, $p_{max} - p_{min}$. The table gives for each threshold setting the optimum index, a possible gas mixture having that index, and the momentum range of K/π discrimination.

Table I1

T	n-1	Gas	Momentum Range (GeV/c)
1	$140x10^{-6}$	65:35 Ne-N_2	13-30
2	$200x10^{-6}$	40:60 Ne-N_2	12.5-26
3	$285x10^{-6}$	N_2	9.5-22
4	320	75:25 N_2-CO_2	9.5-21

At T = 1 it is possible to cover the range 13 - 30 GeV/c by using a gas with n = 1 + 140 x 10^{-6}. This index could be achieved at atmospheric pressur by a 65:35 Ne:N_2 mixture. At T = 2 the greatest momentum coverage is obtained with n = 1 + 200 x 10^{-6}, 12.5 - 26 GeV/c. This index is attainable with a 40:60 Ne-N_2 mixture.

With pure nitrogen and T = 2, the momentum range is 8-21 GeV/c. To cover a low momentum band in a second run, one could fill with Freon-12 (n - 1 = $1080x10^{-6}$); at T = 2 the momentum coverage is 3-11 GeV/c.

The π-detection efficiency increases with increasing momentum, from 95% at $p = p_{min}$ to $\geq$ 99% at $p = p_{mqx}$. For T = 2 and n - 1 = $200x10^{-6}$, the pion detection efficiency at 26 GeV/c is 99%, while only 5% of the kaons of this momentum masquerade as π's. The average π:K rejection factor in the band is between 20:1 and 100:1.

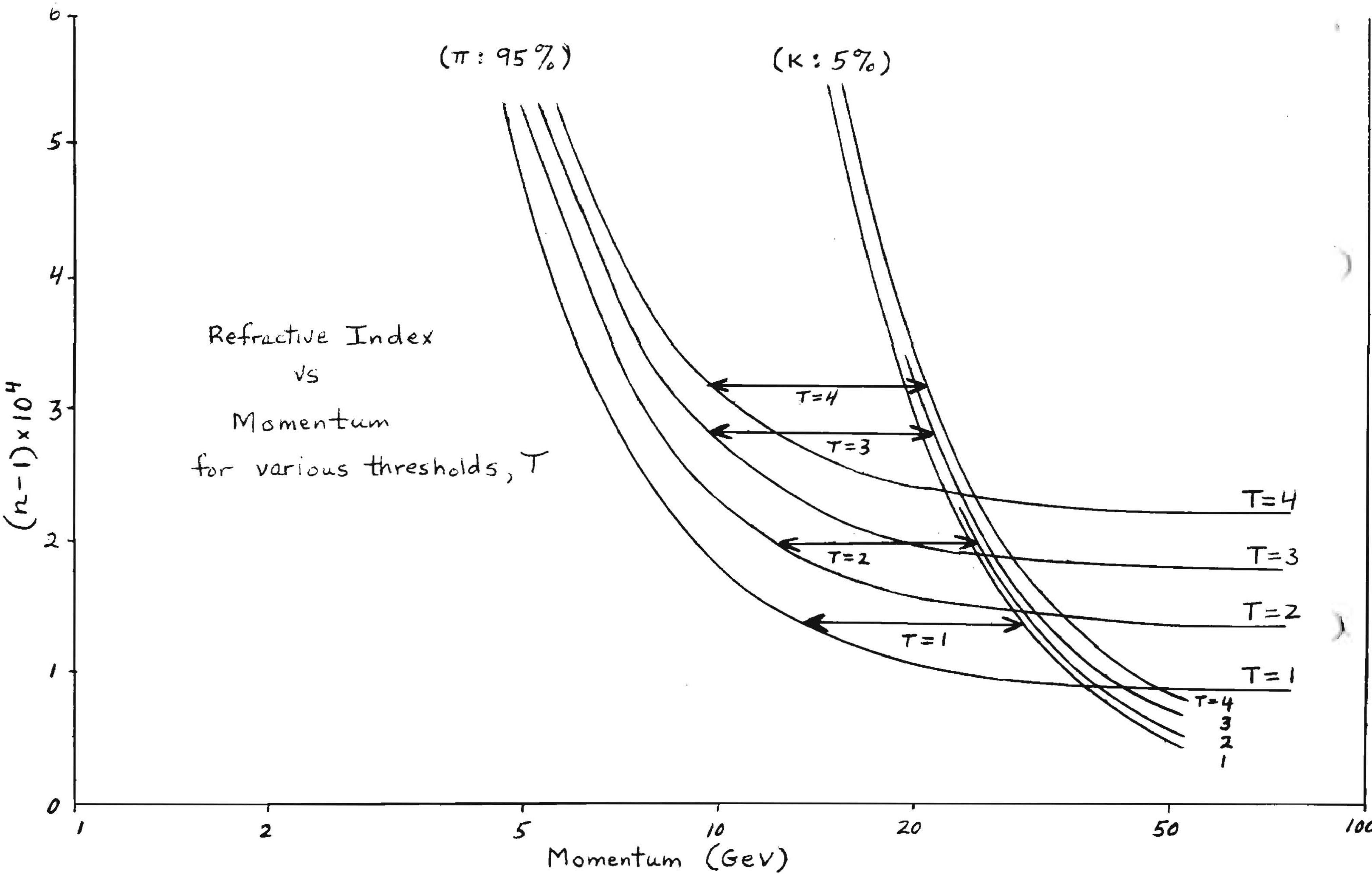

(π : 95%)
(K : 5%)
Refractive Index
vs
Momentum
for various thresholds, T
$(n-1)\times 10^4$
T=4
T=3
T=2
T=1
T=4
3
2
1
0
1
2
3
4
5
6
1
2
5
10
20
50
100
Momentum (GeV)

Figure I1

FERMILAB PROPOSAL No. 369

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A Search for Charmed Particles

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A Search for Charmed Particles

→ PRELIMINARY ←

Proposal to Fermilab by

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above imply that the final states of charmed objects will contain many particles, and that very good multi-particle mass reconstruction and very large acceptance will be required to identify the associated productions. We believe the Muon Scattering Spectrometer is the best instrument for pursuing the search. We elaborate on this view and propose a specific experiment below. The nomenclature of GLR is used for definiteness.

The most useful and striking prediction for the decay of low lying charmed particle states is the weak conversion of charmed quarks into strange quarks giving rise to the decay selection rule for the charmed quark current:

$$\Delta C = \Delta S = \Delta Q$$

Thus, the lowest lying charmed particles will preferentially decay into states with a different net strangeness. This property, in turn, results in an abundance of final state kaons for both strange and non-strange charmed particles. We will exploit this kaon abundance to trigger on processes with a substantially enriched proportion of charmed particles. The selective trigger is necessary first because the fraction of all interactions containing charmed particles is estimated to be at the level of 10^{-3}, and secondly, because reconstruction of the parent particle masses will require that there be no missing neutrals in the decays. The specific trigger scheme is described in the appropriate section and depends basically on detection of the sequence:

$$\bar{K}^\circ, K^\circ \rightarrow K_S \rightarrow \pi^+\pi^-$$

In this way, both the kaon mass and the parent charmed particle mass will be seen to be specifically determined and measured.

Up to this point, we have been very non-specific about the detailed properties expected from the particles that we seek. This is because we plan to impose as few prejudices as possible, the irreducible minimum being

a) the masses be not more than a few GeV,

b) the lowest lying states decay preferentially into kaons,

c) associated production of charmed particles is the production mechanism.

We therefore aim at detecting the inclusive production of charm/anticharm states with a bias toward forward going particles. It is helpful, however, to be somewhat more specific about the properties of the particles we expect to see in order that the method of searching be clearer.

It is likely that the lowest lying charmed particle states are a triplet of charmed pseudoscalar mesons D°, D^{+}, F^{+}, where the D's are non-strange and the F^{+} has strangeness +1. There are also multiplets of charmed vector mesons presumed to be higher in mass and a non-charmed singlet vector meson ϕ_c made up of charmed quarks in analogy to the ordinary ϕ meson. The lowest lying baryon states belong to a 15-plet and likely have masses higher than the mesons. All the masses can be calculated by first order symmetry breaking of SU4 in terms of the assumed masses of the four underlying quarks. GLR introduce a splitting parameter R defined by:

$$\text{i)} \qquad R = \frac{m_c - m_u}{m_s - m_u}$$

where u, s, c are labels for the up, strange, and charmed quarks respectively. The scaling is assumed to be linear in mass for baryons and quadratic for mesons as in SU3. The scaling laws which result are:

$$\text{ii)} \qquad m_D^2 - m_\pi^2 = m_F^2 - m_K^2 = R(m_K^2 - m_\pi^2)$$

$$\text{iii)} \qquad \frac{1}{2}(m_{\phi_c}^2 - m_\rho^2) = R(m_{K^*}^2 - m_\rho^2) \quad .$$

$$\text{iv)} \qquad m_{c_1} - m_p = m_{T_0} - m_\Xi = m_s - \left(\frac{3m_\Lambda + m_\Sigma}{4}\right) = R(m_\Sigma - m_p)$$

$$\text{v)} \qquad m_{c_0} - m_p = m_A - \left(\frac{3m_\Sigma + m_\Lambda}{4}\right) = R(m_\Lambda - m_p)$$

$$\text{vi)} \qquad m_{x_{a,d}} - m_p = m_{x_s} - m_\Sigma = R(m_\Xi - m_p) .$$

If we identify the 3.1 GeV particle recently found at SLAC and BNL with ϕ_c, we can solve iii) for the value of R. The result is R = 21.5. Given R, we can calculate the other masses to obtain:

Particle	mass (GeV)
D	2.22
F	2.26
C_0	4.74
C_1	6.33
$X_{u,d}$	9.17
X_s	9.42

We are cautioned by GLR not to rely on these predictions to the level that the SU3 formulas work for known multiplets, but it is clear that masses are in a clearly accessible range for efficient Fermilab production and detection.

Given the picture outlined above, we propose to examine the following inclusive processes in a 200 GeV beam.

vii) $p + N \to C^{++} + D^- + X$

$C^{++} \to D^+ p$

$D^+ \to \bar{K}^\circ \pi^+$

$\bar{K}^\circ \to K_s \to \pi^+\pi^-$

$D^- \to K^\circ \pi^-$

$K^\circ \to K_s \to \pi^+\pi^-$

ix) $\pi^\mp + N \to D^+ D^- + X$

$D^+ \to \bar{K}^\circ \pi^+$

$\bar{K}^\circ \to K_s \to \pi^+\pi^-$

$D^- \to K^\circ \pi^-$

$K^\circ \to K_s \to \pi^+\pi^-$

N is taken to be a proton or carbon nucleus. The states shown should be produced diffractively in the positive X domain and will have favorable acceptance in the spectrometer. The numerical details are obviously complicated and are discussed in the section on rates. Here we state the important overall observation namely that a very large acceptance for charged particles is needed in order to analyze the seven or more charged particles necessary to demonstrate the associated production. To our knowledge, the CCM is the only triggerable device at Fermilab capable of doing an adequate job on this.

It is equally important to observe at this point that the ability to trigger on a restricted class of events is essential for an effective search since the charmed events are rare. We estimate on the basis of known facts that no more than about 0.4% of all inelastic interactions will result in a pair of charmed particles in the final state. This basic fraction will be subject to further degradation by the requirements of reconstructability. All told, even with the superior acceptance of the CCM spectrometer, only about 5 events per million inelastic interactions will yield a fully reconstructed charmed event. The restrictive trigger we propose increases the yield to one event per thousand triggers, a gain of a factor 200. A one per thousand yield is a doable experiment.

The basic acceptable trigger rate for the apparatus as it stands is about 10/burst which gives a 40% dead time. If our event/trigger yield is $.9 \times 10^{-3}$, this is an event rate of 10^{-2}/burst or about 4 events per hour. A beam of about 100K per burst is required to achieve this rate. It has already been shown to be easy to get hadron fluxes of this intensity into the CCM spectrometer.

The mass resolution of the spectrometer is a complicated function of the energies and multiplicities of the parent particles. What we can say in general is that the resolution should be no worse than 50 MeV FWHM over the majority of the phase space and is considerably better in some regions. If the ratio of charmed particles to all K° events is 4% as postulated, the signal to noise ratio for a single D meson relative to all K°π masses reconstructed mass is as shown in Fig. 4. We see that there is a clear signal. In the fraction of events in which <u>both</u> D's are reconstructed, the effect is much more dramatic. We conclude that our mass resolution is adequate for the job.

This, therefore, represents an overview of the salient points of the proposal. The following sections will discuss in some detail the rates, backgrounds, trigger scheme, run plan, analysis plan and logistics.

Apparatus

The basic apparatus considered is that of the Muon Scattering Facility (MSF) system with appropriate modifications. We propose to replace the liquid hydrogen target with a solid target, e.g. 2 cm of scintillator which would give a 3.6% interaction probability. No recoil proton analysis will be performed.

The trigger makes use of the fact that charmed mesons are expected to have a substantial branching ratio into final states which include neutral K° mesons. Thus, the reaction $pp \to D^+D^-pp$ could lead via $D^+ \to \overline{K^o}\pi^+$ and $D^- \to K^o\pi^-$ to the final state $K^o\overline{K^o}\pi^+\pi^-pp$.

We therefore look for events in which the two neutral K's decay via $K^o_S \to \pi^+\pi^-$. A small thin scintillation counter is placed immediately downstream of the production target. The pulse height in this counter is analyzed to determine the number of minimum ionizing particles passing through. A hodoscope placed two meters downstream then will detect the number of particles passing through it. When the number is observed to increase from 3 to 7 or, more generally, from n to n+4, then the spark chambers are fired. Additional veto counters and downstream hodoscope requirements will also be added to the trigger.

Fig. 1 shows the target configuration. The elements B and HV represent beam defining and halo veto counters respectively. A discrimination threshold slightly higher than the single minimum ionization level will be set for the target counter T1. A differential level of 3 is set for counter T2 and a threshold level of 7 is set for the counter hodoscope TH. Hodoscopes downstream of the analyzing magnet will be set to require 7 particles. Fig. 2 shows the calculated effects of Landau fluctuations in T2. The curves indicate, e.g. that 3 particles can be distinguished from 5 particles with 90% efficiency. The 10% misidentified events contribute to the overall inefficiency of the trigger but do not contribute to the background trigger rate.

Downstream Spectrometer

We propose to employ the equipment now in use by Exp. 98 without changes. The geometry of the spectrometer is shown in Fig. 3. A set of 8 multiwire proportional chambers (1m x 1m, 1.6mm wire spacing) records the tracks between the target and the magnet. Two sets of wire spark chambers (a set of 12 2m x 4m planes and a set of 8 2m x 6m planes) record the tracks after the spectrometer. The two 2m x 4m counter hodoscopes G and H provide a rough counting of the number of forward particles. Downstream of these there is a 2m x 4m x 5 cm steel γ-converter and a set of WCS (8 2x4 meter planes) to detect electron showers.

Beam

The beam should have the highest momentum obtainable in order to improve the spectrometer acceptance. An intensity of 2×10^5 protons/1 sec. pulse at 200 GeV/c is adequate. Previous tests have indicated that this is feasible.

On-Line Computer

It would be hoped that the Σ-3 currently in use at the MSF could be used. If this is not the case then a PDP-11 would have to be obtained from FNAL.

Off-Line Computer

We would like to have $\sim$ 50 hours of CDC-6600 time to do data reduction on samples of data while running.

Rates for observation of $D\overline{D}$ States

Our basic trigger requires the production of a $K^\circ\overline{K^\circ}$ pair and the decay of both K° and $\overline{K^\circ}$ within a fiducial length of about 2 meters. We will discuss later the contribution of $K^\circ\Lambda^\circ$ to the trigger rate. The fraction of measurable D and/or $\overline{D}$ among the triggers involves basically an answer to two questions:

(a) What is the ratio of inclusive $D\overline{D}$ production to inclusive $K\overline{K}$ production?

(b) What are the branching ratios for the various D decays?

To get explicit results we have made the following assumptions:

(a) The rate of inclusive D^+D^- production is 1/50 of the rate of inclusive $K^\circ\overline{K^\circ}$ production. We assume equal rates for the remaining $D\overline{D}$ channels (i.e., $D^+\overline{D^\circ}$, $D^\circ\overline{D^\circ}$ and $D^\circ D^-$).

(b) We have used the branching ratios estimated by GLR for $M_D = 2$ GeV, together with Clebsch-Gordon coefficient (we assume all $K\pi$ states to have $I = 1/2$).

Explicitly, we assume

$D^+ \to \overline{K^\circ}\pi^+$	51%	(M)
$\to \overline{K^\circ}\pi^\circ\pi^+$	13%	
$D^\circ \to \overline{K^\circ}\pi^\circ$	17%	
$\to \overline{K^\circ}\pi^-\pi^+$	17%	(M)
$\to \overline{K^\circ}\pi^\circ\pi^\circ$	4%	

Where (M) refers to a decay mode where all decay products are (potentially) measurable.

We now proceed in turn to estimate the trigger rate due to $K^\circ\overline{K^\circ}$, the trigger efficiency and the fraction of triggers containing fully measured D or $\overline{D}$ decays.

1. Basic trigger rate

We assume a target 0.03 of an interaction length (for instance 2 cm. of plastic scintillator).

We calculate the trigger rate per incident beam track as follows:

Fraction of beam tracks interacting	0.03
Fraction of events with $K^\circ\overline{K^\circ}$	0.1
Probability that each K° decays	$(1/3 \times 0.7)^2$
	1.2×10^{-4}

In addition we will have fake triggers involving a secondary interacting in one of the counters which count the number of tracks before and after the decay volume.

We estimate this rate as follows:

Fraction of beam tracks interacting	0.03
Total counter thickness (in interaction length)	0.0055
Average number of secondaries	4
Fraction of secondary interactions which fake $n \to n+4$ requirement	1/4
	1.7×10^{-4}

With a beam intensity of 10^5 particles/sec. and a deadtime of 30 milliseconds, one would get

$$(2.9\times10^{-7}\times10^{5})/(1+.03\times29) = 15 \text{ triggers per burst.}$$

The fraction of $K^\circ\overline{K^\circ}$ triggers is 0.4.

2. Fraction of fully measured D and/or $\bar{D}$ decays per trigger

Consider as the simplest example the production and decay of D^+D^-;

$D^+D^- \to (\overline{K^\circ}\pi^+) + (K^\circ\pi) \to (\pi^+\pi^-\pi^+) + (\pi^+\pi^-\pi^-)$

This rate relative to the rate for $K^\circ\overline{K^\circ} \to (\pi^+\pi^-) + (\pi^+\pi^-)$ is ..

ratio of D^+D^- to $K^\circ\overline{K^\circ}$	1/50
B.ratio for $D^+ \to \pi^+\pi^-\pi^+$	0.51
B.ratio for $D^- \to \pi^+\pi^-\pi^-$	0.51
Probability that either D^+ or D^- or both are fully measured	0.3
	1.6×10^{-3}

The detection efficiency was estimated by assuming the usual p_T, p_{11} distributions in inclusive production and by tracing the decay tracks through the apparatus.

The above contribution gives:

Fully measured D^+ or D^- per raw trigger

Fraction of $K^\circ\overline{K^\circ}$ per trigger	0.4
Ratio of "good events" to $K^\circ\overline{K^\circ}$ trigger	1.6×10^{-3}
	0.6×10^{-3}

Including the contributions of the remaining channels considered at the beginning of the section, one gets instead of the above:

Ratio of "good events" to all triggers 1.2×10^{-3}

Up to now we have not included triggers due to $K^\circ\Lambda^\circ$ production and decay.

We estimate $\dfrac{K^\circ\Lambda^\circ \to (\pi^+\pi^-) + (p\pi^-)}{K^\circ\overline{K^\circ} \to (\pi^+\pi^-) + (\pi^+\pi^-)}$ ~ 4 for pp; ~ 2 for πp

This reduces the trigger efficiency (ratio of $K^\circ\overline{K^\circ}$ triggers to all triggers) by a factor of 0.45 for pp and 0.70 for πp.

If we neglect the contribution of $C \to pD$ to the signal, we finally obtain:

$$\frac{\text{Good Event}}{\text{Raw Trigger}} = 0.6\times10^{-3} \text{ for pp}$$
$$= 0.9\times10^{-3} \text{ for } \pi\text{p} .$$

Logistics

The people proposing this experiment likely do not represent a complete experimental group. Instead, it is presented in the spirit of an elaborate letter of intent and much of the detailed work remains to be done. Enough material is hopefully included to demonstrate feasibility and stimulate interest in this approach. The proposers would be happy to join with like-minded others and promise to supply Addenda in the near future elaborating on the material included here. At any rate, we feel that observation of charmed particles in an experiment insensitive to the details of particle masses and specific decay modes, and one which has the advantage of showing explicitly the associated production of <u>both</u> mesons and baryons is of extremely high interest and importance.

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2. Private communication from members of SLAC Group of Ref. 1.

3. Search for Charm, Mark K. Gaillard, *et al.*, Fermilab-Pub-74/86-THY (1974).

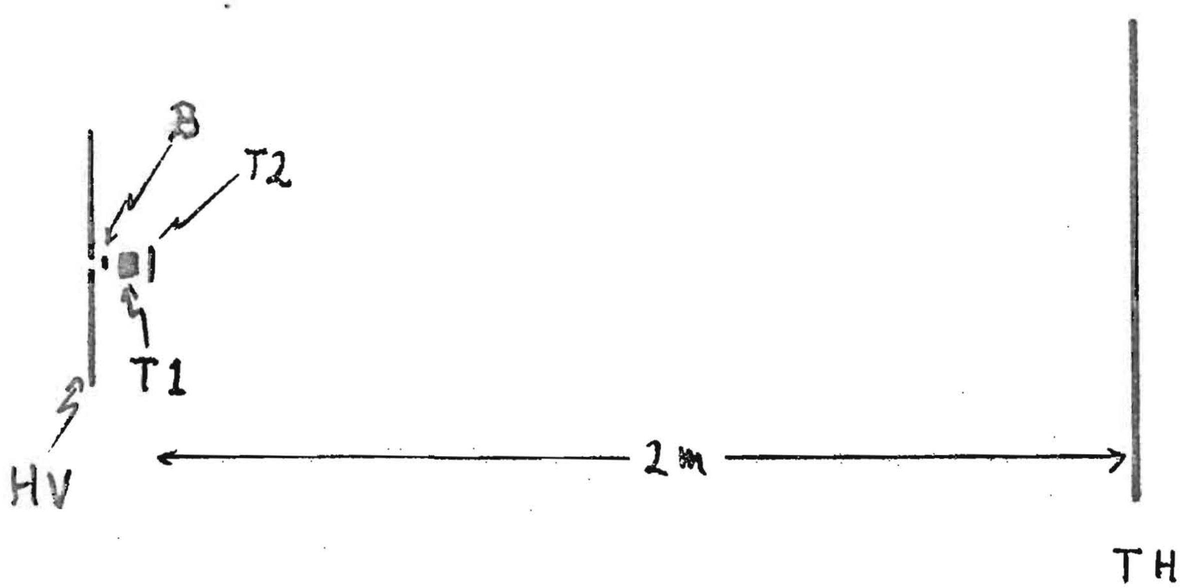


Fig. 1. Layout of target region

HV - Halo Veto counter

B Assorted beam defining counters (schematic)

T1 Line target counter 3 cm. thick

T2 Particle number counter 1.5 mm. thick

TH Particle number hodoscope. 20 elements.

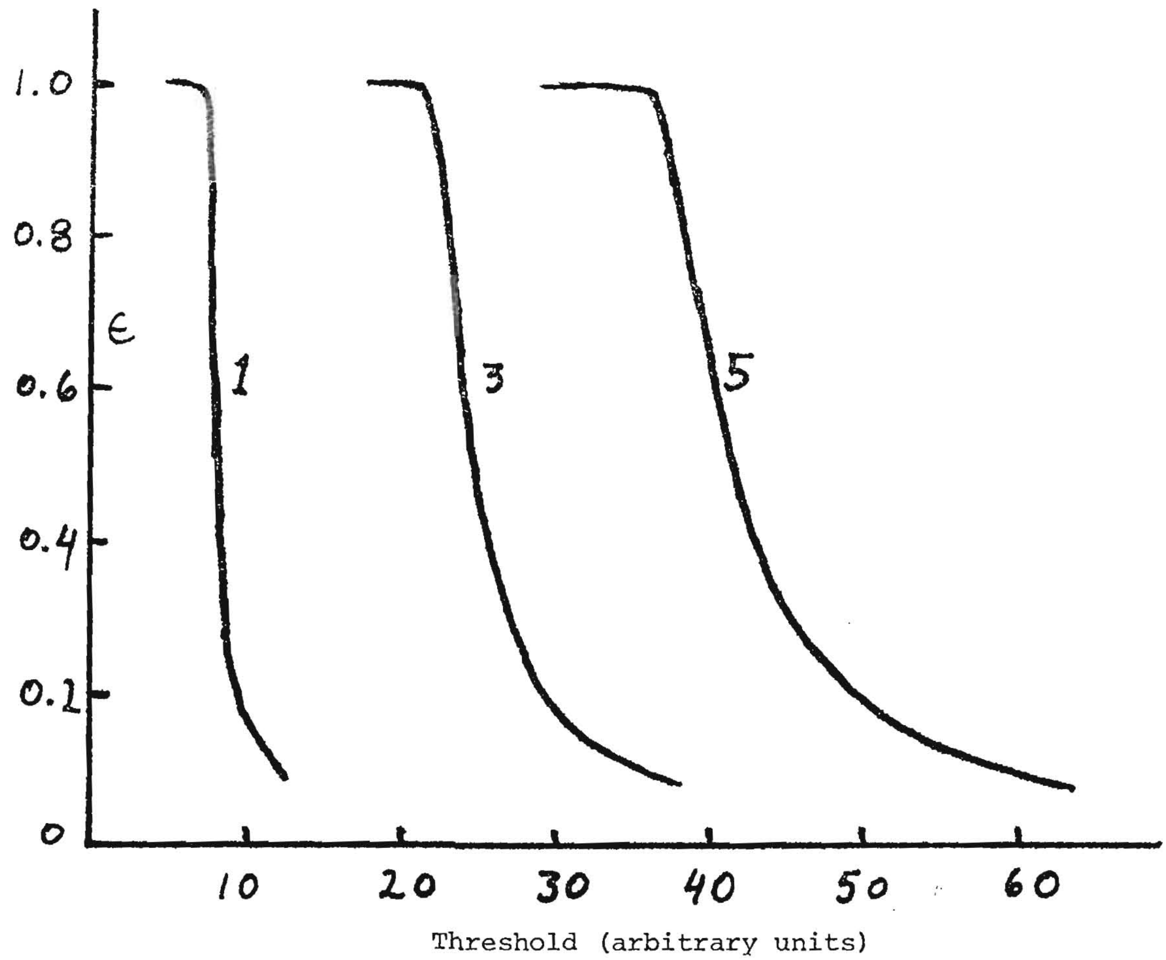
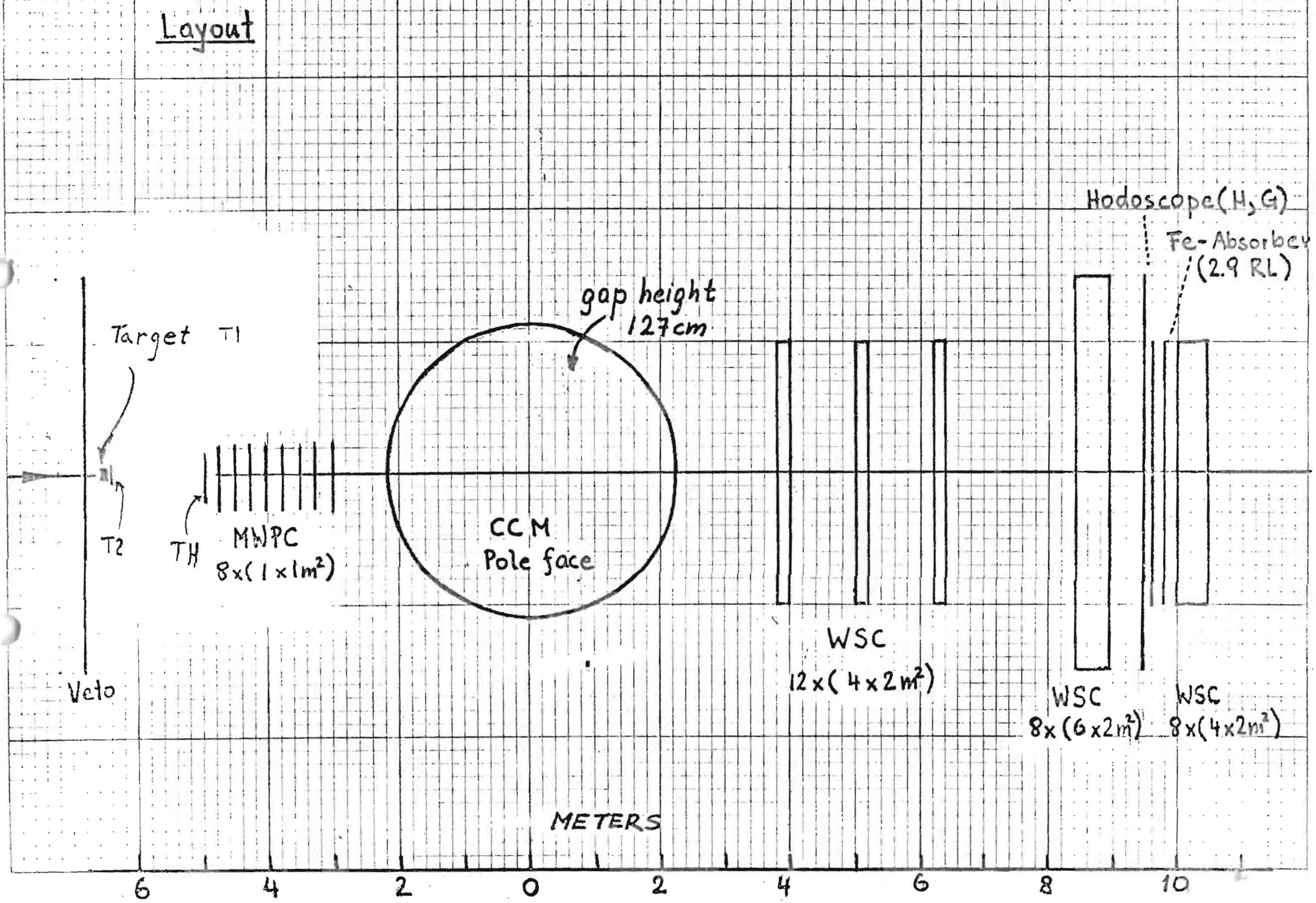


Fig. 2. Efficiency vs. discriminator threshold for 1, 3, and 5 minimum ionizing particles through a 1 mm. counter. (According to Landau).

FIG 3


Layout
Hodoscope(H, G)
Fe-Absorber
(2.9 RL)
gap height
127cm
Target
T1
T2
TH
MWPC
8x(1x1m²)
CCM
Pole face
WSC
12x(4x2m²)
WSC
8x(6x2m²)
WSC
8x(4x2m²)
Veto
METERS
6
4
2
0
2
4
6
8
10

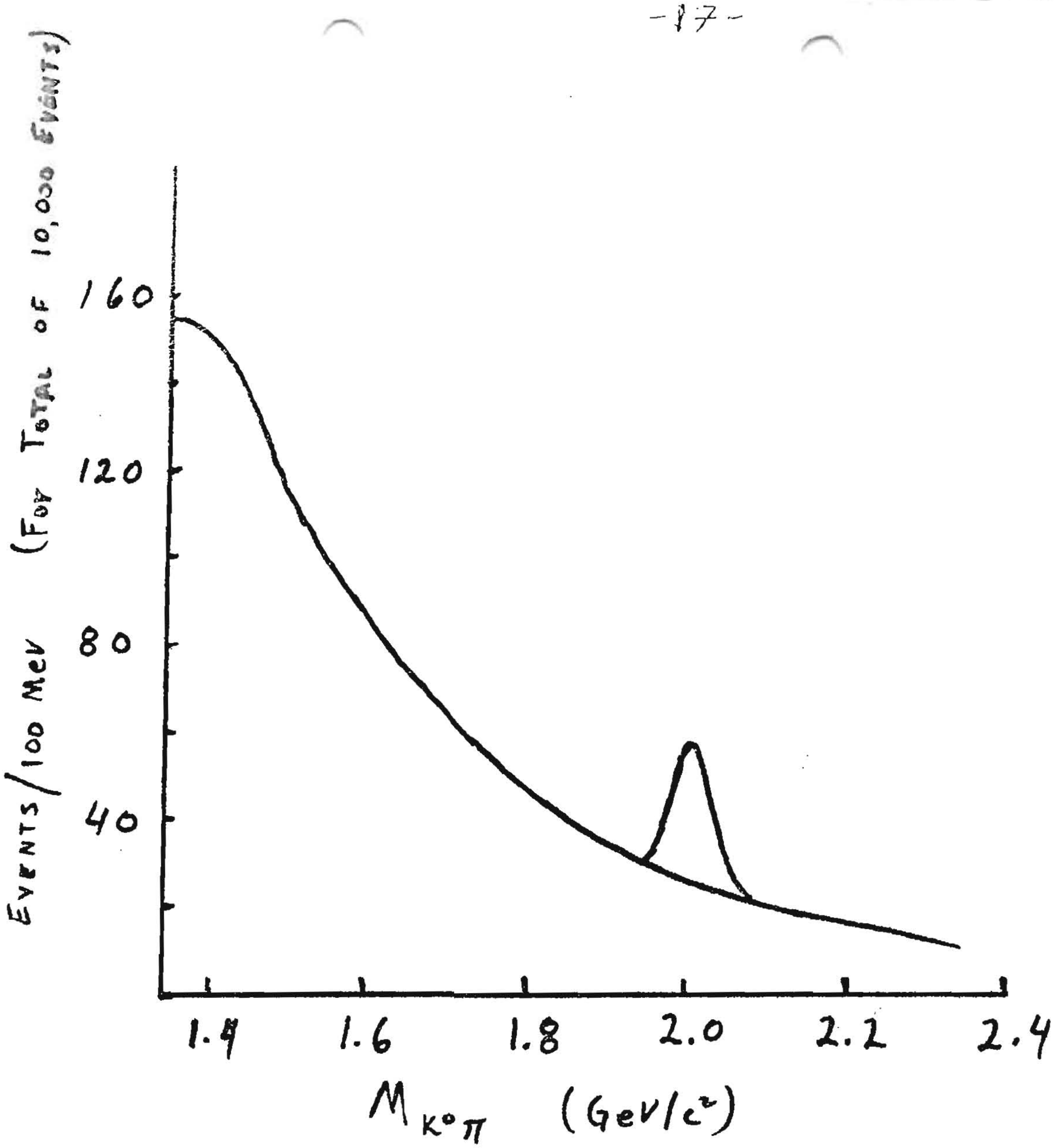


Figure 4. Effective mass of K°π system due to assumed background.